EPA Regional Priority AFO Science Question Synthesis Document

Manure Management

Workshop Review Draft:

Supporting Documentation for the EPA Regional Science Workshop on Animal Feeding Operations (AFOs) - Science and Technical Support Needs

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5.1 Animal Wastes and Pollutant Movement from AFOs

Waste handling and manure management practices at animal feeding operations (AFOs) are closely tied to the variety of animal management, feeding, and housing practices used in the animal production industry. Although there are still many operations at which animals are raised outdoors, economic efficiencies have driven segments of the industry (e.g., swine and poultry) toward larger, total confinement facilities. Confinement structures may prevent contact of precipitation and runoff with the animals and manure, minimizing generation of large volumes of contaminated storm water runoff and the movement of pollutants from animal confinement areas (USEPA, 2002a). Thus these operations do not need to manage large, episodic volumes of storm water runoff, only the precipitation falling directly into manure-handling and storage structures (e.g., lagoon or open tank).

At large beef, dairy, and heifer operations animals are raised in confined outdoor lots. Large surface areas are exposed to precipitation, generating large volumes of storm water runoff contaminated with manure, bedding, feed, silage, antibiotics, and other process contaminants. Such operations must manage storm water runoff from open lots (e.g., by storm water diversion, solid separation, vegetated filter strips) as well as the storm water that contacts food or silage.

Beyond facility storm water issues, both confinement and outdoor operations produce large amounts of wastes that are typically applied to the land. AFOs annually produce more than 500 million tons of animal manure (USEPA, 2003) that, when improperly managed, can pose substantial risks to the environment and public health. Most animal waste contains numerous chemical and biological constituents such as the nutrients nitrogen (N), phosphorus (P), and potassium (K); heavy metals; and pathogens that can potentially contaminate the environment.

Application to agricultural land is the most common disposal/utilization practice for animal waste (Kellogg, et al., 2000) because it is an inexpensive method of disposal. For example, approximately 95% of swine production sites applied manure to land owned or rented by the site (Walton, 2002), about 99% of beef feedlots applied manure to land (USDA APHIS 1995), roughly 99% of dairy operations applied manure to land (USDA APHIS, 1996), and more than 40% of the litter generated by poultry growers is land applied (Kusher, 2002). Unfortunately, land applied animal waste is also a potential source of contamination (Wood, et al., 1999; Landry and Wolfe, 1999; Choudhary, et. al., 1996; Westerman, et al., 1987). Agricultural lands have been identified as the principal non-point source of contaminants accounting for as much as 73% of the biochemical oxygen demand (BOD), 92% of the total suspended solids, and 83% of the bacteria present in U.S. waterways (Landry and Wolfe, 1999).

Livestock operations may not always have adequate land available to safely apply and use manure constituents. In an analysis of the 1997 Census of Agriculture data, the U.S. Department of Agriculture (USDA) found that potential concentrated animal feeding operations (CAFOs) accounted for 64 percent of the farm-level excess nitrogen and 67 percent of the farm-level excess phosphorus. USDA also determined that about 6 percent of livestock operations with confined animals in 1997 had no acres available for manure application (Kellogg, et al., 2000). Application of excessive amounts of manure nutrients increases the risk that these nutrients reach surface or ground water or volatilize to the atmosphere.

5.1.1 Pathways

Once applied to the land, manure constituents may be moved to surface or ground waters by a number of pathways (Figure 5-1). Initial movement is generally driven by precipitation or snowmelt, but can also be initiated by irrigation. Particulate materials at the land surface can be detached by raindrop impact or by the force of runoff water; manure constituents can also be dissolved in water and moved with surface runoff. Manure pollutants may then be transported by overland flow to the edge of the field or to a waterway. Constituents on or within the soil may be dissolved and moved downward toward the ground water with infiltrating water where they may be intercepted by tile drains and delivered to receiving waters. Nitrogen may enter the atmosphere through volatilization of ammonia from applied waste.

5.1.2 Pollutants

Nitrogen is the plant nutrient most often deficient in non-legume crops and farmers apply

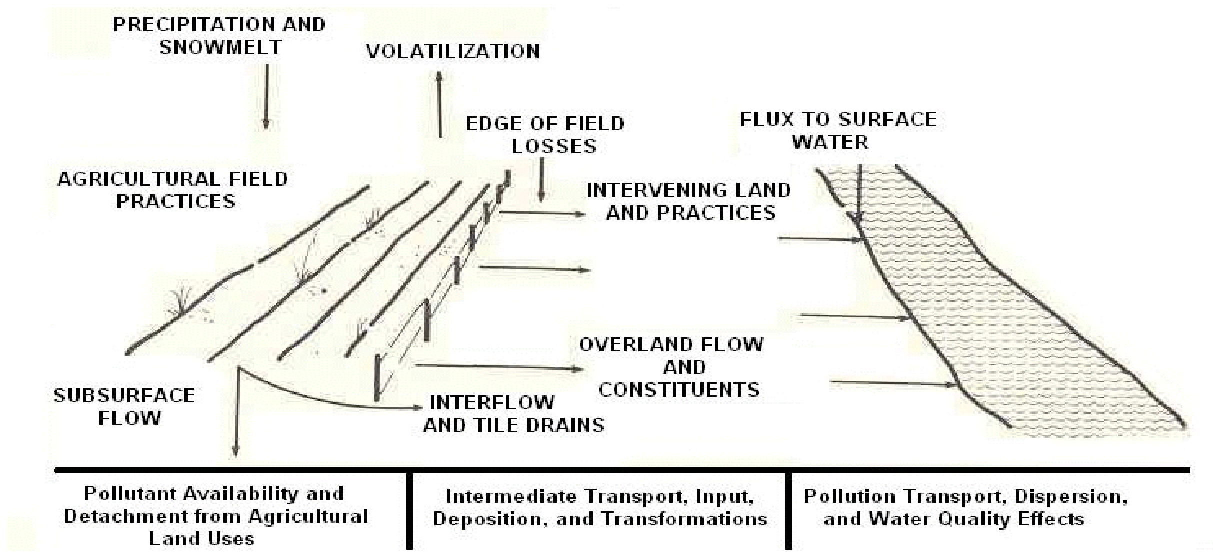

Figure 5- 1. Principal transport mechanisms for pollutant loss

N to promote desirable crop yields. There are some risks to adding nitrogen to the soil, including leaching of nitrate nitrogen (NO3-N) to groundwater and runoff of excessive N to estuaries and other surface waters (McLeod and Hegg, 1984; Robinson, and Sharpley, 1995, Skaggs and Chescheir, 1999), whether the source is commercial fertilizer or an organic material such as manure. Continual, excessive application of manure can lead to surface soil accumulation of N in cropland (Sharpley, DCN 21420), along with NO3-N concentrations in surface runoff above permissible public water supply standards (McLeod and Hegg, 1984). Research has shown that the total nutrient runoff of ammonium nitrate ranges between four to seven percent of the total land applied (McLeod, 1984). Edwards and Daniels (1991) reported 37 percent of the total N in surface-applied poultry manure was lost to the atmosphere due to volatilization in 11 days following application.

Land application of manure is not the only source of nitrogen in the soil. Atmospheric deposition of N can be a significant component of the N budget of many water bodies such as Chesapeake Bay (Boynton et al., 1995). Nitrogen can also leach into the soil from waste and feed storage structures. Ammonium nitrogen concentrations above 1000 mg/liter N have been measured in shallow monitoring wells around clay lined animal waste lagoons on the Delmarva Peninsula (Ritter and Churnside, 1990).

Increased phosphorus concentrations is a significant water quality problem associated with land application of animal waste. A major imbalance arises when manure is applied to cropland because the ratio of N to P in manures (typically around 2:1 to 3:1) is so much lower than plant N:P uptake ratios (typically ranging from 4.5:1 to 9:1). If manure is applied to provide adequate N for a crop, the amount of P added to the soil with this manure is two to three times greater than the P needs of that crop. This inevitably leads to P accumulation in the soil and has the potential to create an environmental problems (Shreve, et al., 1984; Satter, 2000; and Sharpley, 1997). Continued inputs of fertilizer and manure P in excess of crop requirements have led to a build-up of soil P levels in many areas (Sharpley, et al., 1994). For example, beef feedlot waste applied in Texas contributed an excess of 700 lb P per acre, dairy manure applied in Wisconsin contributed an excess of 400 lb P per acre, poultry litter applied in Oklahoma contributed an excess of 560 lb P per acre, and swine slurry applied in Oklahoma contributed an excess of 300 lb P per acre relative to the nutrient needs of crops (Sharpley, 1997).

The build-up of soil P levels has resulted in P transport from waste application fields to waterbodies during rainfall runoff events (McFarland, et al., 1999) and can be the major portion of P transported from most cultivated land (60-90%) (Sharpley, et al., 1992). Phosphorus leaves agricultural fields as dissolved phosphorus and particulate phosphorus attached to soil sediment (Voss and Griffith, 1999). The scope of this situation is illustrated in Figures 5-2 and 5-3. The first map (Figure 2), created by the (Kellogg, 2000), identifies the areas of the United States that have a surplus of P produced on animal feeding operations relative to the assimilative capacity of the crops. Figure 3 (Sharpley et al., 1999), identifies states where the majority of the agricultural soils have soil test P levels in the “high” or “above” categories. When comparing the maps, note that the areas with significant excess nutrients align well with the areas containing soils high in phosphorus. A linear relationship has been shown to exist between mass losses of P and application rate and rainfall intensity, with mass losses increasing as both application rate and rainfall intensity increase (Edwards and Daniel, 1992; Voss and Griffith, 1999).

Numerous microorganisms found in the intestinal tracts of warm-blooded animals are excreted in waste. While numbers vary by species, farm livestock typically shed about 10^6 to 10^7 fecal coliform organisms per gram of waste, or approximately 10^9 - 10^{10} organisms per capita per day (Robbins et al. 1971, Reddy et al. 1981, Moore et al. 1988). Indicator organisms such as E. coli and fecal coliform are commonly found in surface waters draining agricultural land, usually in numbers exceeding water quality criteria (e.g., Crane et al. 1983, Baxter-Potter and Gilliland 1988, Meals 1989 and 2001, Niemi and Niemi 1991, Howell et al. 1995, Crowther et al. 2002). In addition to benign indicator bacteria that may cause violations of water quality standards, other microorganisms from livestock operations may directly threaten human health. Pathogenic

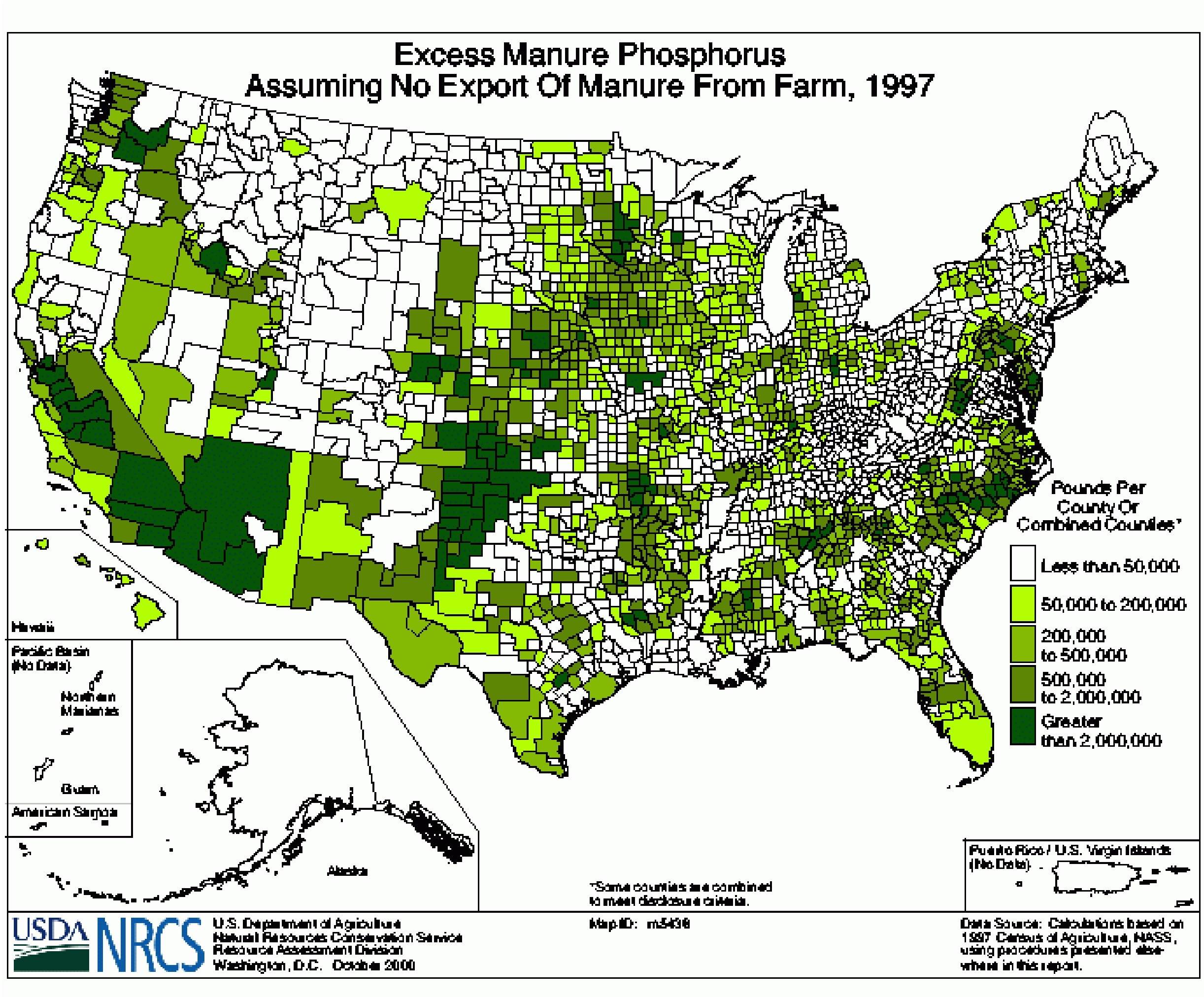

Figure 5- 2. Surplus Phosphorus Production from Animal Feeding Operations

organisms such as Salmonella, Campylobacter, Listeria, Yersinia, Mycobacterium, Leptospira, Cryptosporidium, Giardia, and E. coli O157:H7 are sometimes found in animal manures and may be transmitted to the environment (Stehman et al. 1996).

The collection, storage, management, and distribution of animal waste within a farm operation create several distinct reservoirs of microorganisms. Concentrated animal holding areas accumulate manure and consequently represent important stocks of fecal microorganisms. Runoff from concentrated animal holding areas may contain 10^5 - 10^8 fecal coliform organisms/100 ml. Some studies have shown that runoff from barnyards laden with stacked animal wastes may have the highest microbial pollution potential of any agricultural activity (Moore et al. 1983). Land application of animal waste may deliver 10^9 - 10^{12} E. coli per acre to the land annually. Depending on subsequent precipitation, runoff, and land management, microorganisms in the land-applied waste may be available for transport and delivery to surface or ground waters. Fecal coliform counts of 10^4 - 10^6 /100 ml in runoff from manure application areas are commonly reported (Crane et. al., 1983, Baxter-Potter and Gilliland 1988, Moore et al. 1988). Various studies have estimated that between 1 to 25% of microorganisms from applied animal waste may be lost in runoff annually (Robbins et al. 1971, Kunkle 1970, Faust, 1976).

Soil Samples (%) Testing High or Above

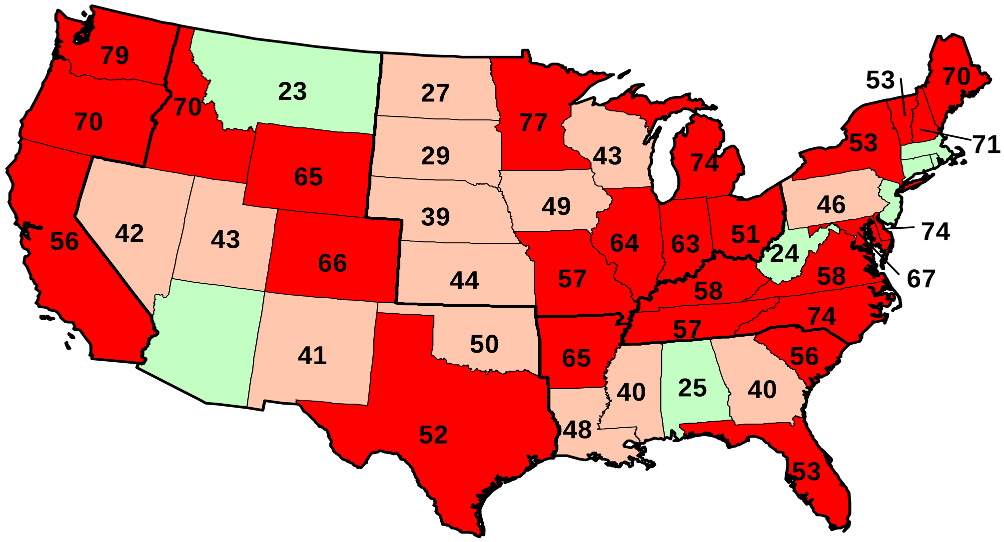

Figure 5- 3. Percentage of Soil Samples Testing High or Above for Phosphorus

Animals on pasture deposit microorganisms with their manure, representing a loading to the land over a significant portion of the year. Livestock access to streams can be a source of direct deposit of microorganisms to surface waters.

5.2 Waste Management Functions at AFOs

Waste management at all confined AFOs includes a series of fundamental activities as shown in Figure 5-4: waste production, waste collection, waste transfer, waste storage, waste treatment, and waste utilization (USDA, 1992). The specifics of these activities differs by the type of livestock produced. For example, dairy waste management (Figure 5-5) may include production from a barn, open lot, and milking center; collection by scraping, pumping, or solids separation; storage in a stacking facility, lagoon, or other structure; treatment in a lagoon or through composting; and waste utilization by liquid or solid spreading or irrigation (USDA, 1992). Poultry waste management (Figure 5-5) may include waste production from poultry house litter and routine mortality, collection by scraping, flushing, or under-house pits; storage in a stacking facility or lagoon; treatment through composting or incineration; and utilization by land application (USDA, 1992). Regardless of the specific pathways of waste management in a particular AFO, pollution control strategies and practices can be applied to each of the stages in waste management.

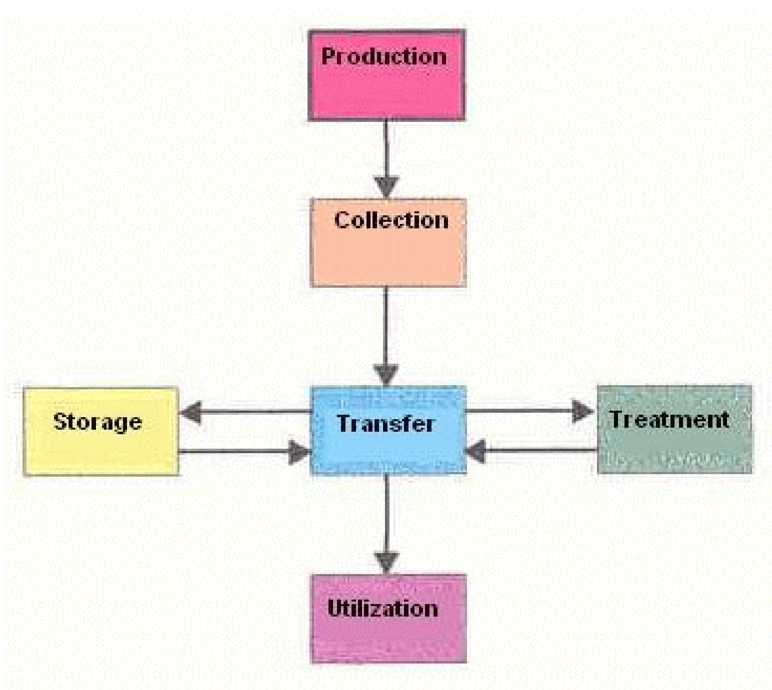

Figure 5- 4. Waste Management Functions

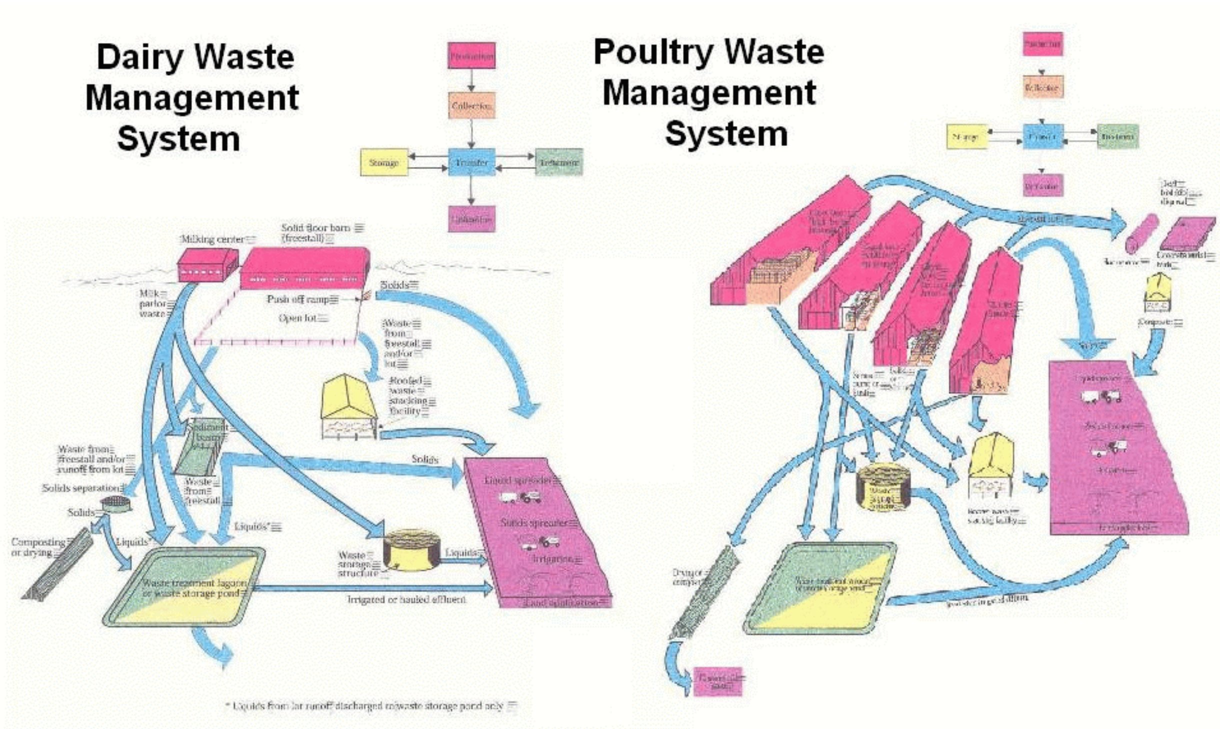

Figure 5- 5. Dairy and Poultry Waste Management Options

5.2.1 Waste Production

Production area practices include feeding strategies that can reduce the concentration of pollutants in waste and practices. Feeding strategies designed to reduce N and P losses include more precise diet formulation, enhancing the digestibility of feed ingredients, genetic enhancement of cereal grains and other ingredients resulting in increased feed digestibility, and improved quality control. These strategies increase the efficiency with which the animals use the nutrients in their feed and decrease the amount of nutrients excreted in the waste. With a lower nutrient content, more manure can be applied to the land, fewer livestock operations will be land-limited, and less cost will be incurred to transport excess manure from the farm. Strategies that focus on reducing P concentrations, thus reducing overapplication of P and associated runoff into surface waters, can turn manure into a more balanced fertilizer in terms of plant requirements. Feeding strategies that reduce nutrient concentrations in waste have been developed for specific animal sectors. Specific examples of changes in feeding formulations and strategies include:

- **Precision Nutrition for Swine**. Current swine feed rations can result in overfeeding proteins and other nutrients to animals because they are designed to ensure that nutritional requirements are met and growth rate maintained. Precision nutrition entails formulating feed to meet more precisely the nutritional requirements of animals, causing more of the nutrients to be metabolized, thereby reducing the amount of nutrients excreted (NCSU, 1998).

- **Improved Feed Preparation for Swine**. Milling, pelleting, and expanding are examples of technological treatments that improve the digestibility of feeds. By reducing the particle size, the surface area of the grain particles is increased, allowing greater interaction with digestive enzymes (Vanschoubroek et al., 1971.)
- **Feed Additives for Swine**. Plant P is often present in the form of phytate, which is digested poorly by swine, resulting in most of the P in feedstuffs being excreted in the manure. The enzyme additive phytase has been shown to improve P digestibility dramatically, and can be used to reduce the need for digestible P additives (Lei et al. (1993).
- **Use of Phytase as a Feed Supplement for Poultry**. Poultry are deficient in the enzyme phytase and cannot break down the protein phytate; much of the P contained in feed cannot be digested by poultry and up to 75 percent of the P contained in feed grains is excreted in manure (Sohail and Roland, 1999; NCSU, 1999). Supplementing poultry feeds with phytase improves digestibility of P and reduces P excretion in poultry waste.
- **Precision Nutrition for Poultry** Greater understanding of poultry physiology has led to the development of computer growth models that take into account a variety of factors including strain, sex, and age of bird, for use in implementing a nutritional program. By optimizing feeding regimes using simulation results, poultry operations can increase growth rates while reducing nutrient losses in manure.
- **Genetically Modified Feed for Poultry.** Genetically modified corn developed by the USDA-Agricultural Research Service (ARS) stores most of its seed P as P rather than as phytate. The P in the modified corn is more easily available to the consuming animal (Iragavarapu, 1999).
- **Reducing Dietary Phosphorus for Dairy Cattle.** Evidence indicates that dairy operators, as a whole, may be oversupplying P in dairy diets. Reduction in manure P levels would lead to a more favorable N:P ratio, favoring the production of a more balanced fertilizer. Reducing the amount of P in dairy diets has also been shown to reduce production costs and increase overall profitability, and has no ill effects on animal health or reproduction (Van Horn, 1991).
- **Animal Feed Grouping for Dairy Cows.** Grouping strategies offer another method of realizing gains in nutrient efficiency. When grouping does not occur and the whole herd receives the same diet, cows may receive suboptimal diets and nutrient export via manure may be greater. Using grouping strategies to their greatest effect to improve nutrient efficiency would entail individualized diets (Dunlap et al., 1997).
- **Optimizing Crop Selection.** Optimizing crop selection is another potential strategy for reducing nutrient losses in combination with dairy diets to meet annualized herd feed requirements. For example, some crop mixes may perform better than others with respect to N losses per unit of N in milk or meat (Kohn et al., 1998). Furthermore, producing more quality feed on the farm may help reduce imports of feed (and the P and N feeds contain), improve nutrient recycling within the farm, and achieve a better whole-farm nutrient balance.

5.2.2 Waste Collection

Several practices are available that reduce the water content of the waste stream. Reducing water content may improve the handling characteristics of the waste and make waste transfers easier and less costly due to reductions in weight and volume. The production of a drier waste can be accomplished by three methods: (1) handling the waste in a dry form, (2) reducing the use of water at the AFO, or (3) separating the solid fraction of the waste from the liquid fraction. Most poultry operations currently handle their waste in a dry form, and this section generally does not apply to these operations. It should be noted that except for improvements that reduce the potential for concentrated waste discharges or losses in farmstead storm water runoff, changes in waste collection systems by themselves rarely have major pollution control benefits. It is the ultimate management of the waste that influences water quality. Examples include:

- **Dry Scrape Systems and the Retrofit of Wet Flush Systems.** Scraper systems are a means of mechanically removing manure, and they can be used to push manure through collection gutters and alleys similar to those used in flush systems. Retrofitting a wet flush system with a dry scrape system involves reconstructing the existing manure handling equipment within a livestock housing structure. A scraper blade replaces flowing water as the mechanism for removing manure from the floor of the structure.
- **Gravity Separation of Solids.** Gravity settling, separation, or sedimentation are simple means of removing solids from liquid or slurry manure by taking advantage of gravitational forces. In agricultural applications, gravity settling is a primary clarification step to recover solids at a desired location where they can be managed easily, thereby preventing those solids from accumulating in a downstream structure where they would be difficult to manage. A wide range of gravity separation practices is used in agriculture, including sand and rock traps, picket dams, and gravity settling basins designed to retain 1 to 12 months' accumulation of solids.
- **Mechanical Solid-Liquid Separation.** Solids-liquid separation is used to recover solids prior to their entry into downstream liquid manure facilities. Solids recovery reduces organic loading and potential accumulation of solids and improves the pumping characteristics of animal manure. Mechanical separation equipment is used to reduce the space required for separation, to produce a consistent separated solid product amenable to daily handling, to produce a liquid product that is easily pumped for spreading, or to recover specific particle sizes for other uses such as bedding.

5.2.3 Waste Transfer

Manure collected from within a barn or confinement area must be transferred to the storage or treatment facility. In the simplest system, the transfer component is an extension of the collection method. More typically, transfer methods must be designed to overcome distance and elevation changes between the collection and storage facilities.

The method used to transport manure depends largely on the consistency of the manure. Liquids and slurries can be transferred through open channels, pipes, and in liquid tank wagons.

Pumps can be used to transfer liquid and slurry wastes as needed; however, the greater the solids content of the manure, the more difficult it will be to pump. Solid and semisolid manure can be transferred by mechanical conveyance or in solid manure spreaders. Slurries can be transferred in large pipes by using gravity, piston pumps, or air pressure. Gravity systems are preferred because of their low operating cost.

Many animal feeding operations use manure waste and wastewater on site as fertilizer or irrigation water on cropland; however, nutrient management plans require that facilities apply only the amount of nutrients agronomically required by the crop. When a facility generates more nutrients in its manure waste and wastewater than can be used for on-site application, they must transport the remaining manure and wastewater off site.

Animal feeding operations use different methods of transportation to remove excess manure and wastewater from the feedlot operation. Manure is transported as either a solid or liquid material. For most operations, solid waste is transported before liquid waste because it is less expensive to haul per unit of nutrient moved.

One method evaluated for transporting manure waste off site is contract hauling, whereby the operation hires an outside firm to transport the excess waste. This method is advantageous to facilities that do not have the necessary capacity to store excess waste on site or the cropland acreage to agronomically apply the material. In addition, this method is useful for operations that do not generate enough excess waste to warrant purchasing their own waste transportation trucks. Contract haulers can transport waste from multiple operations. Costs are dependent upon the distance the manure is transferred, the type of animal waste, and the form of animal waste (solid vs. liquid). Contract haulers typically charge less than $0.55 per ton per mile for beef and dairy wastes and less than $0.23 per ton per mile for swine and poultry wastes. Typically, waste hauling at swine and poultry operations is accomplished via contracts.

Several states have developed programs to provide support to animal producers who have excess manure and need to find an alternative mean of managing it in order to help alleviate the concentration of excess nutrients in the soils of crop and pasture fields. For example the Maryland Department of Natural Resources (MD DNR) has created a program subsidizing the cost of transporting animal manure to make it affordable for animal producers to remove excess manure and providing an incentive for the development of alternatives technologies and business ventures to create a market for use of animal manures. In 2003 commercial poultry companies paid fifty percent of the cost of transporting poultry and reimbursement for all participants was capped at $20 per ton (MD DNR 2004a).

In 1998, the MD DNR and the Wicomico Soil Conservation District joined in a cooperative project designed to demonstrate that transporting poultry litter from the watershed and replacing that crop nutrient source with inorganic fertilizers can have water quality benefits. As a result of the transporting all of the poultry litter from the watershed, the nutrient surpluses in the watershed have decreased about 92 percent for nitrogen and 98 percent for phosphorus (MD DNR 2004b). Resulting, improvements in water quality have been documented.

5.2.4 Waste Storage

Waste storage is a common practice that allows for central collection of manure and other farm-generated wastes (e.g., milking center waste, wash water) so that waste can be managed properly. In cold climates, for example, storage is essential in order to avoid winter spreading of manure. Winter manure applications should generally be avoided because of the high potential for runoff losses during snowmelt and the inability to incorporate manure into the soil where nutrients and bacteria could be immobilized (USEPA, 2002a). Storage is a virtual necessity for implementation of a nutrient management plan. It must be emphasized that in general, waste storage alone is not a practice that will protect water quality; it is the management of the stored waste that affects water quality. There are a few exceptions to this principle. First, in cases where waste storage includes capturing of all farmstead runoff and other wastes such as milking center wastes and silage leachate (for example, under the Florida Dairy Rule), waste storage will help eliminate the other sources as discrete problems. Second, waste storage alone is highly effective in reducing the microorganism content of animal waste (see below).

Waste storage systems vary widely according to the type of livestock and type of operation. Some examples of storage systems include:

- **Pit/Lagoon Storage.** Manure pits are a common method for storing animal wastes. They can be located inside the building underneath slats or solid floors, or outside and separated from the building. Typical storage periods range from 5 to 12 months, after which manure is removed from the pit and transferred to a treatment system or applied to land. There are many design options for pit storage.
- **Lagoon Liners.** Lagoon liners are impervious barriers used to reduce seepage through the lagoon bottom and sides. Geomembranes and geosynthetic clay liners are the most impervious types of liners if designed and installed correctly (USDA, 1992). Synthetic liner systems can consist of a layer of packed clay topped with a synthetic liner. A lagoon can also be lined solely with compacted clay soil. The compacted clay soil liner must be inspected carefully to verify the soils, compaction, and thickness and tested by an independent laboratory to verify a permeability equal to or less than the design value. Compacted clay soil liners should be avoided in karst areas.
- **Litter Storage Sheds.** Litter from broiler and turkey operations is stored on the floor of the housing facility and transported to fields for land application (USDA, 1992). If land application is not possible because of field conditions or other factors, the litter is stored outside of the housing facility until it can be transported for treatment or land application. In some climates compacting the stack may be sufficient to alleviate the problem for short term storage, but storing the litter in a shed with a roof and a floor is a better alternative in areas where there is a concern that there may be leaching of contaminates from unprotected stacked manure.
- **Belowground or Aboveground Storage Tanks.** Belowground and aboveground storage tanks are used as an alternative to under-building pit storage and earthen basins. Both aboveground and belowground tanks are commonly constructed of concrete or steel.

5.2.5 Waste Treatment

Some treatment systems store waste as well as change the chemical, physical, or biological characteristics of the waste. Engineered systems like anaerobic lagoons are the most common form of treatment for AFOs. Other technologies use oxidation to break down organic matter. These include aerated lagoons for liquids and composting for solids. Additional treatment options include chemical amendments to change nutrient forms or reduce pathogens and vegetative treatment of concentrated waste sources.

5.2.5.1 Engineered Waste Treatment

Examples of engineered waste treatment options include:

- **Passive waste storage for microorganism reduction**. Considerable research has documented extensive die-off of microorganisms in manure storage without special treatment; reduction of fecal coliform levels by 2 - 3 orders of magnitude is typical with storage for 2 - 6 months (Moore et al., 1983; Patni et al., 1985; Walker et al., 1990). Patni et al. (1985) reported median fecal coliform counts of 0.5 x 10^6/g in fresh manure (mix of dairy, beef, and poultry) compared to 0.1 x 10^3/g in manure stored for 6 - 30 weeks in outdoor tanks. Trevisan and Dorioz (1999) observed that fecal coliform and fecal streptococci counts in dairy manure decreased by ~2 logs after 4-6 months storage. Conboy and Goss (2001) reported these declines in bacteria counts in stored dairy manure:

Day	Fecal coliform (#/100 ml)
1	100,000
28	10,000
63	1,000
119	5

  In a recent literature review, Jamieson et al. (2002) concluded that long-term storage of livestock wastes prior to land application has the greatest impact on reducing bacterial transport from agricultural land to water.

- **Anaerobic Lagoons.** Anaerobic lagoons are earthen basins that provide storage for animal wastes while decomposing and liquefying manure solids. Anaerobic processes degrade high BOD wastes into stable end products without the use of free oxygen. Anaerobic lagoons are designed based on volatile solids loading rates (VSLR). Volatile solids are the wastes that will decompose.

  Anaerobic lagoons offer several advantages over other methods of storage and treatment. Anaerobic lagoons can handle high pollutant loads and provide a large volume for long-term storage. They stabilize manure wastes and reduce N content through biological degradation. Lagoons allow manure to be handled as a liquid, which reduces labor costs. If lagoons are located at a lower elevation than the animal barns, gravity can be used to transport the waste to the lagoon, which further reduces labor. Mild climates are most suitable for lagoons; cold weather reduces the biological activity of the microorganisms that degrade the wastes. Lagoons can experience spring and fall turnover, in which the more odorous bottom material rises to the surface. Foul odors can also result if biological activity is reduced or if there is a sudden change in temperature or pollutant loading rate.

- **Anaerobic Digesters for Methane Production and Recovery.** Anaerobic digestion is the decomposition of organic matter in the absence of oxygen and nitrates. Under these anaerobic conditions, the organic material is stabilized and is converted biologically to a range of end products, including methane and carbon dioxide. Anaerobic treatment reduces BOD, odor, and pathogens, and generates biogas (methane) that can be used as a fuel. The methane-rich gas produced during digestion may be collected as a source of energy to offset the cost of operating the digester. Liquid and sludge from the system are applied to on-site cropland as fertilizer or irrigation water, or are transported off site.

  An anaerobic digester is a vessel that is sized both to receive a daily volume of organic waste and to grow and maintain a steady-state population of methane bacteria to degrade that waste into biogas over time. Anaerobic digestion can also enhance microorganism die-off. Anaerobic digestion at mesophilic temperatures (35°C) reportedly decreased E. coli numbers by 90% in less than one day during batch digestion, in contrast to bacteria survival in manure slurry of up to 77 days (Stehman et al., 1996). Some advantages of anaerobic digestion include the opportunity to reduce fuel bills, produce more stabilized manure, reduce odor and fly breeding potential, and conserve nutrients in solids.

- **Aerobic Treatment of Liquids.** Conventional aerobic digestion is an option for all swine and poultry operations where manure is handled as a liquid or slurry, and it can be used with flushing systems using either mixed liquor or clarified effluent as flush water. With proper process design and operation, a 75 to 85 percent reduction in 5-day BOD (BOD5) appears achievable, with a concurrent 45 to 55 percent reduction in chemical oxygen demand (COD), and a 20 to 40 percent reduction in total solids (Martin, 1999). In addition, a 70 to 80 percent reduction of the N in both poultry and swine wastes via nitrification-denitrification also appears possible. Total P is not reduced, but the soluble fraction may increase. As with aerobic digestion of biosolids, some reduction in pathogen densities may also occur depending on process temperature.

  In addition to the potential for substantial reductions in oxygen- demanding organics and N, one of the principal advantages of aerobic digestion of poultry and swine manures is the potential for a high degree of odor control. Another advantage is the alleviation of fly and other vermin problems. Limitations include high energy requirements for aeration and mixing (e.g., pumps, blowers, or mixers for mechanical aeration), space requirements for the shallow lagoons, and the absence of a reduction in the volume of waste requiring ultimate disposal. Also, management, maintenance, and repair requirements for aerobic digestion systems can be significant. For example, liquids and solids must be separated in a pretreatment step when aerated lagoons are used. BOD removal rates for aerobic digestion are summarized in Table 5-1.

- **Autoheated Aerobic Digestion.** Autoheated aerobic digestion uses heat released during the microbial oxidation of organic matter to raise process temperature above ambient levels. Mesophilic temperatures, 86ºF (30ºC) or higher, can typically be maintained even in cold climates, and thermophilic temperatures as high as 131 to 149ºF (55 to 65ºC) can be attained. Both ammonia stripping and nitrification-denitrification can be mechanisms of N loss at mesophilic temperatures; nitrification-denitrification is typically the principal mechanism if the aeration rate is adequate to support nitrification. Heating also helps reduce pathogen content.

- **Secondary Biological Treatment.** The activated sludge process treats organic wastes by maintaining an activated mass of microorganisms that aerobically decomposes and stabilizes the waste. It is a widely used technology for treating wastewater that has high organic content. Properly designed, installed, and operated activated sludge systems can reduce the potential pollution impact of feedlot waste because this technology has been shown to reduce carbon-, N-, and P-rich compounds.

  In the activated sludge process, N is treated biologically through nitrification-denitrification. The supply of air facilitates nitrification, which is the oxidation of ammonia to nitrite and then nitrate. Denitrification takes place in an anoxic environment, in which the bacteria reduce the nitrate to nitrogen gas (N_2), which is released into the atmosphere. The activated sludge process can nitrify and denitrify in single- and double-stage systems. P is removed biologically when an anaerobic zone is followed by an aerobic zone, causing the microorganisms to absorb P at an above-normal rate. The activated sludge technology most effective for removing P is the sequencing batch reactor (SBR) (see "Sequencing Batch Reactors," below). N and P can both be removed in the same system. The SBR is also most effective for targeting removal of both N and P because of its ability to alternate aerobic and anaerobic conditions to control precisely the level of treatment.

Table 5-1. Operational Characteristics of Aerobic Digestion and Activated Sludge Processes.

Process Modification	Flow Model	Aeration System	BOD Removal Efficiency (percent)	Remarks
Conventional	Plug flow	Diffused-air, mechanical aerators	85–95	Use for low-strength domestic wastes. Process is susceptible to shock loads.
Complete mix	Continuous-flow stirred-tank reactor	Diffused-air, mechanical aerators	85–95	Use for general application. Process is resistant to shock loads, but is susceptible to filamentous growths.
Step feed	Plug flow	Diffused air	85–95	Use for general application for a wide range of wastes.
Modified aeration	Plug flow	Diffused air	60–75	Use for intermediate degree of treatment where cell tissue in the effluent is not objectionable.
Contact stabilization	Plug flow	Diffused-air, mechanical aerators	80–90	Use for expansion of existing systems and package plants.

Extended aeration	Plug flow	Diffused-air, mechanical aerators	75–95	Use for small communities, package plants, and where nitrified element is required. Process is flexible.
High-rate aeration	Continuous-flow stirred-tank reactor	Mechanical aerators	75–90	Use for general applications with turbine aerators to transfer oxygen and control floc size.
Kraus process	Plug flow	Diffused air	85–95	Use for low-N, high-strength wastes.
High-purity oxygen	Continuous-flow stirred-tank reactors in series	Mechanical aerators (sparger turbines)	85–95	Use for general application with high-strength waste and where on-site space is limited. Process is resistant to slug loads.
Oxidation ditch	Plug flow	Mechanical aerators (horizontal axis type)	75–95	Use for small communities or where large area of land is available. Process is flexible.
Sequencing batch reactor	Intermittent-flow stirred-tank reactor	Diffused air	85–95	Use for small communities where land is limited. Process is flexible and can remove N and P.
Deep-shaft reactor	Plug flow	Diffused air	85–95	Use for general application with high-strength wastes. Process is resistant to slug loads.
Single-stage nitrification	Continuous-flow stirred-tank reactors or plug flow	Mechanical aerators, diffused-air	85–95	Use for general application for N control where inhibitory industrial wastes are not present.
Separate stage nitrification	Continuous-flow stirred-tank reactors or plug flow	Mechanical aerators, diffused-air	85-95	Use for upgrading existing systems, where N standards are stringent, or where inhibitory industrial wastes are present and can be removed in earlier stages.

Source: Metcalf and Eddy Inc., 1991.

- **Sequencing Batch Reactors.** An SBR is an activated sludge treatment system in which the processes are carried out sequentially in the same tank (reactor). The SBR system may consist of one reactor, or more than one reactor operated in parallel. The activated sludge process treats organic wastes by maintaining an aerobic bacterial culture, which decomposes and stabilizes the waste.

  SBR technology could be applied to reduce the potential pollution impact of liquid manure waste from dairies because this technology has been shown to reduce compounds rich in carbon, N, and P. Removing these pollutants from the liquid portion of the waste could allow for greater hydraulic application to lands without exceeding crop nutrient needs. Concentrating the nutrients in the sludge portion could potentially reduce transportation volumes and cost of shipping excess waste. Although a proven technology for treatment of nutrients in municipal wastewater, available data do not exist showing SBRs to be effective in pathogen reduction.

  Given the processes it employs, SBR treatment may allow treated dairy wastewater to be either applied to land or discharged to a stream if a sufficient level of treatment can be achieved. Further, the sludge from the wasting procedure could be applied to land, composted, or sent off site for disposal. The use of SBRs to treat dairy waste has been studied in the laboratory at both Cornell University and the University of California at Davis. Both studies have shown SBR technology to be effective in reducing pollutants in the liquid portion of dairy waste, although neither report included specific information on sludge characteristics or P removals (Johnson and Montemagno, 1999; Zhang et al., 1999).

In the Cornell study, diluted dairy manure was treated in bench-scale reactors (Johnson and Montemagno, 1999). Experiments were conducted to determine the operating strategy best suited for the diluted dairy manure. The study resulted in removals of 98 percent of ammonia (NH_3), 95 percent of COD, 40 percent of nitrate/nitrite (NO_3/NO_2), and 91 percent of inorganic N.

The University of California at Davis studied how SBR performance was affected by HRT, SRT, organic loading, and influent characteristics of dairy wastewater (Zhang et al., 1999). The highest removal efficiencies from the liquid portion of the waste were for an influent COD concentration of 20,000 mg/L (a COD concentration of 10,000 mg/L was also studied) and an HRT of 3 days (HRTs of 1 to 3 days were studied). With these parameters, laboratory personnel observed removal efficiencies of 85.1 percent for NH3 and 86.7 percent for COD.

In addition, studies on SBR treatment of swine waste in Canada and of veal waste in Europe have demonstrated high removal rates of COD, N, and P (Reeves, et al., 1999).

- **Composting.** Composting essentially uses heat to accelerate microbial decomposition, with three major types of composting systems in vogue: aerated static pile, windrow, and in-vessel. Composting is not typically used for wet manure, but it can be used for solid manure or solids separated from slurries, as well as for the disposal of smaller animals such as poultry. Swine have been successfully composted by shredding, grinding, or cutting up the carcass into smaller pieces. Animal composting facilities typically consist of an enclosure in which carcasses are layered with manure and a bulking material, the mix of which is critical in determining the success of the process.

Reports of the effectiveness of composting for pathogen reduction have been conflicting. If properly managed, composting may offer significant initial reductions of bacteria numbers due to high temperatures, but regrowth of bacterial populations after temperatures decline has been reported. Because bacteria have been reported to increase to numbers approaching those in original dairy waste solids, some authors suggested that unless done very carefully, composting offers little benefit toward net reduction of bacteria in dairy waste.

Pell (1997) reported E. coli survival time in composting manure to be 70 d at 5°C, 56 d at 22°C, and 49 d at 37°C. Although composting caused rapid initial declines in E. coli, a stable population was retained for an extended period. A similar observation was made by Mote et al. (1988) who observed that total coliform counts declined rapidly in initial stages of composting, but as internal temperatures declined, bacteria increased to numbers approaching those in original dairy waste solids. In a recent Canadian study, Larney et al. (2003) reported more than 99.9% elimination of E. coli and total coliform in open-air windrow composting of dairy manure. Most of the bacteria reduction occurred in the first seven days, when average composting temperatures ranged from 33.5 to 41.5°C. The authors recommended composting as a means to minimize environmental risks of manure application. At the same time, they cautioned that pathogen inactivation is time and temperature dependent and predicted recovery and regrowth of pathogen populations if inactivation is incomplete.

5.2.5.2 Chemical Amendments to Stabilize Nutrients

Recently, interest has increased in the use of amendments or treatments to stabilize P in animal waste to less soluble forms and thereby decrease the risk of soluble P losses following land application of waste. Cost data are lacking, however, as many of these treatments have not been applied broadly. Lowering pH through alkaline additions also helps decrease ammonia volatilization from manure. For example:

- **Water treatment residuals.** Water treatment residuals (WTR), also known as alum sludge or alum hydrosolids (HS), are wastes generated from drinking water pretreatment. Peters and Basta (1996) added HS to soils previously treated with poultry litter and reported 50 - 60% reductions in Mehlich-III P; the authors noted that most treatments did not result in excessive soil pH or increases in heavy metals in soils. Haustein et al. (2000) found that high rates of both WTR and HiClay Alumina (HCA) applied directly to test plots decreased Mehlich-III soil test P levels due to the increased levels of soil Al; runoff concentrations of aluminum were not significantly increased relative to the control.
- **Ferric Chloride.** Ferric Chloride additions to poultry litter decreased P solubility at lower rates of about 20-50 g Fe/kg litter, but increased solubility at higher rates (Moore and Miller 1994). Barrow et al. (1997) reported that adding high levels of ferric chloride to dairy wastewater improved sedimentation of P by almost 50%. Sherman et al. (2000) reported significant P removal from dairy flushwater using ferric chloride. Note that removing P from a waste stream using ferric chloride or any other flocculant leaves a solid residue that requires proper management.
- **Coal combustion byproducts.** Stout et al. (1998) reported that addition of fluidized bed combustion flyash (FBC) and flue gas desulfurization product (FGD) to soils significantly reduced Mehlich-III P (45%), Bray-I P (50%), and water extractable P (72%) due to converting readily desorbable soil P to less soluble Ca-, Al-, or Fe-bound forms. Dao (1999) observed that application of Class C fly ash to cattle manure reduced water-extractable P by 85-93% and Mehlich-III P concentrations by up to 98%. FBC and FGD additions reduced water soluble inorganic P in fresh dairy and swine manure by 50 - 80% (Toth et al. 2001a). Dou and Ferguson (2002) reported water soluble P reductions of 23-59% in swine and dairy manure treated with FBC and FGD. It should be noted that these byproducts can contain significant concentrations of heavy metals that may be toxic to plants and the loadings of these elements must be considered in the use of combustion byproducts.
- **Zeolite.** Lefcourt and Meisinger (2001) reported that addition of zeolite (primarily Si, AL, Na, and K oxides) to dairy slurry reduced soluble P content by over 50% and reduced ammonia emissions by nearly 50%. No adverse effects were observed with zeolite amendments.
- **Polyacrylamide (PAM).** PAM has been used to reduce sediment, nutrients, and pesticide losses in furrow-irrigated agriculture. In lab and field studies, PAM alone or in

combination with Al and Ca reduced PO4 by 47 -64% in soil column leachate when manure was applied and by approximately 50% in water flowing over surface-applied cattle manure (Entry and Sojka 2000). The authors also reported reductions of 2 to 3 orders of magnitude in fecal coliform bacteria in leachate and runoff from manure application areas following PAM treatment.

- **Limestone dust.** Barrington and Gelinas (2002) reported precipitating about 93% of total P in swine manure into a sludge by the addition of 2% fine limestone dust.
- **Alum.** The most widely proposed and most thoroughly evaluated manure amendment is aluminum sulfate (Al2(SO4)3) - alum. Alum has been used for P precipitation in wastewater treatment for several decades. The use of alum additions to animal waste has been studied extensively since the early 1990s. Applications have ranged from pretreatment of agricultural wastewaters, manure treatment, and soil amendment. While the majority of the studies have focused on the effects on P solubility and runoff, significant effects on nitrogen volatilization and runoff of metals have also been documented. Alum treatment of animal waste, particularly poultry litter, has important beneficial effects as a P best management practice (BMP). These direct effects include:
    - **Reduced P solubility in waste.** Reductions in water-soluble P content of poultry litter and other animal wastes of 70 to >90% have been cited (e.g., Moore and Miller 1994, Moore et al. 1995, Lefcourt and Meisinger 2000, Sims and Luka-McCafferty 2002). This effect has been documented from the laboratory to the farm scale.
    - **Reduced soil P levels.** Use of alum-treated poultry litter significantly reduces soil P. For example, after three years of treating grass plots with alum-amended litter, no significant differences in soil water soluble P were observed when compared to the unfertilized control (Self-Davis et al. 1998, Moore et al. 2000). Alum-amended litter plots had significantly lower Mehlich-III P values compared to equivalently-managed untreated litter plots after two years of litter applications. Use of treated litter can also reduce soil test P on soils already exhibiting excessively high in soil test P levels (Haustein et al. 2000).
    - **Reduced runoff P.** Use of alum-treated animal waste can dramatically reduce P runoff losses compared to untreated waste. Reductions of about ~60 to 90% in soluble P concentrations in runoff have been widely reported from alum-treated poultry litter and other animal wastes (Shreve et al. 1995, Moore et al. 1997, Bushee et al 1998). In several reported cases, P concentrations in runoff from land-applied alum-treated waste were not significantly different from P levels in runoff from un-manured land (Self-Davis et al. 1998, Edwards et al 1999, Moore et al. 2000). Some researchers have cautioned that decreases in P solubility in applied waste will not alter the total mass of P applied and have called for additional research on the long-term solubility of P in soils receiving alum-treated animal waste (Sims and Luka-McCafferty 2002).
    - **Reduced ammonia loss.** Numerous studies have shown that addition of alum to poultry litter can reduce NH_3 volatilization by as much as up to 99% (e.g., Moore et al. 1995, 1998, and 2000). Reduction in ammonia loss from poultry litter not only reduces airborne ammonia inside the poultry house but improves the

fertilizer value of the litter by conserving N. Higher N content in alum-treated litter has been widely documented (Shreve et al. 1995, Kithome et al. 1999, Sims and Luka-McCafferty 2002).

- **Reduced runoff losses of metals.** Alum amendment decreases litter pH and thus should reduce the solubility of metals such as As, Cu, and Zn and the movement of these soluble forms into surface or ground waters (Sims and Luka-McCafferty 2002). Runoff losses of some trace metals that pose significant environmental risk (e.g., copper) have been shown to be lower from land application of alum-treated poultry litter, compared to conventional litter (Moore et al. 1997 and 1998).

These documented effects of alum treatment have led to the conclusion that alum treatment offers great promise as an animal waste management BMP, particularly for poultry production (Moore et al. 1999, Sims and Luka-McCafferty 2002). Benefits of alum treatment of other animal wastes seem to be similar to those observed with poultry litter, including beef cattle waste (Dao 1999), dairy manure (Sherman et al., 2000; Lefcourt and Meisinger, 2000; Toth et al. 2001b), swine waste (Worley and Das, 2000), and horse manure (Edwards et al., 1999).

Long-term studies of alum use have reported few negative impacts. Some concerns over phytotoxic effects of added aluminum have been expressed, but because aluminum solubility is very low in soils limed to target pH for crop production, such effects have been deemed unlikely (Sims and Luka-McCafferty 2002). The same authors call for more research into the long-term solubility of metals such as As, Cu, and Zn in soils receiving alum-treated wastes.

5.2.5.3 Chemical Treatments for Pathogen Control

Various chemical treatments have been proposed to reduce the levels of pathogens and other microorganisms in animal wastes. Proposed approaches include:

- **Animal treatment.** Good biosecurity practices reduce the incidence of actual pathogen presence in manure, thereby reducing the risk of transmission in runoff from agricultural land (Aceto 2002). There is growing interest in techniques to reduce the incidence of the pathogenic bacterium E. coli O157:H7 (a potentially deadly strain of bacteria that occurs within the generic, non-pathogenic group of E. coli) in livestock shortly before slaughter to prevent the pathogen from contaminating the food processing cycle. Approaches include improved animal housing and drinking water supply, and the use of antibiotics, probiotics, and vaccines (HACCP Alliance 2003). Behrends et al. (2002) determined that feed supplements of TascoR, an extract from the seaweed Ascophyllum nodosum, decreased E. coli O157:H7 in fecal and hide samples from beef cattle by up to a factor of three. Researchers are investigating the use of the beneficial bacteria Lactobacillus acidophilus (a bacteria commonly used in yogurt) to reduce the incidence of E. coli O157:H7 in feedlot beef cattle (Moxley 2002).

  However, biosecurity programs and most other animal treatments do not and cannot normally address generic indicator organisms like fecal coliform and E. coli that are a normal part of the animals' digestive system. These microorganisms are a common basis for water quality standards.

An important exception is the use of chlorate (NaClO3) to reduce E. coli in cattle prior to slaughter (Callaway et al.,2002). Chlorate is bactericidal only against nitrate reductase-positive bacteria (e.g., E. coli), and cattle can be treated without harm to the other gastro-intestinal organisms necessary for fermentation and digestion. When supplied in drinking water for 24 hours prior to slaughter, sodium chlorate reduced the population of E. coli O157:H7 in cattle rumen and feces from 10^4 to 10^2 organisms/g and from 10^6 to 10^3 organisms/g, respectively. The treatment also reduced total coliforms and generic E. coli from 10^6 to 10^4 organisms/g through the gastro-intestinal tract.

- **Alkali treatment.** Several methods of animal waste treatment with alkaline chemicals have been proposed to reduce bacteria content:
    - **Lime stabilization.** While there is little direct information in the literature concerning animal waste treatment by lime disinfection, the use of lime materials (calcium oxides) to reduce pathogens and odor in biosolids is commonplace. Lime stabilization is an economical means to meet Class A biosolids requirements (very low pathogen concentrations under USEPA's regulations) (NLA, 2001; Mignotte-Cadiergues et al., 2000); this process may be transferrable to treatment of animal waste.
    - **Lime disinfection.** Lime is reportedly used in Europe as a disinfectant for barn and milking center floors, for disease control in carcass disposal, and for disinfection of animal wastes (NLA 2001). Cooper Hatchery, Inc. (1987) reported that total bacteria counts, molds, and coliform bacteria were decreased from 10^8 organisms/g to 10^2 to 10^3 organisms/g in turkey litter after three days of fermentation following addition of hydrated lime. Hogan et al. (1999) reported that hydrated lime effectively inhibited bacteria in recycled dairy manure bedding in 1 day. Lime was effective on reducing gram-negative bacteria, coliform counts, Klebsiella spp., and streptococci.
    - **Carbonate/alkali.** Diez-Gonsalez et al. (2000) reported on the use of carbonate and alkali to eliminate E. coli from dairy cattle manure. Stored manure with an initial E. coli count of 7.3 x 10^5/gram was treated with carbonate and alkali; after 5 days of incubation, E. coli were no longer detected in the waste. Although no full-scale tests were conducted, the authors proposed that stabilization of dairy manure with sodium carbonate and sodium hydroxide to virtually eliminate E. coli could be done for a cost as low as $10 per cow per year. Jarvis et al. (2001) reported similar results where even low concentrations of sodium carbonate caused a significant reduction in E. coli.

5.2.5.4 Vegetative Treatment

Finally, if concentrated sources of liquid waste exist on the farmstead, the use of vegetated treatment systems (VTSs) is possible. Vegetated filter strips and constructed wetlands are components of VTSs and are not “stand alone” practices. They are usually preceded by a solids separation and storage facility, and may be followed by a storage pond that allows for recycling of water. The effluent from these practices is rarely discharged to surface waters.

- **Vegetated Filter Strips to treat concentrated sources.** Vegetated filter strips (VFS) are sometimes used for treatment when concentrated sources of polluted runoff such as milking center waste or feedlot runoff cannot be diverted to a storage structure for management with manure, vegetated filter strips (VFS) are sometimes used for treatment. This application of a VFS would come under the USDA-Natural Resources Conservation Service (NRCS) practice standard 635, Wastewater Treatment Strip. Such strips are typically engineered to deliver sheet flow over a regular slope with well-maintained vegetation; barnyard or feedlot runoff typically passes through a settling basin to remove large solids and to meter flow to the strip to avoid hydraulic overload. Reports of VFS effectiveness vary widely. Concentration reductions and mass retention of solids and nutrients of 70 percent to more than 90 percent have been reported under favorable conditions (Young et al., 1980; Dickey and Vanderholm, 1981; Walter et al.,1983; Schwer and Clausen,1989). However, VFS treatment effectiveness can diminish rapidly under hydraulic overload or in cold climates. Pollutant reductions of less than 30 percent have been reported in some studies (Schellinger and Clausen,1992; Edwards et al., 1983).

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- **Constructed Wetlands.** Constructed wetlands (CWs) can be an important tool in the management of animal waste by providing effective wastewater treatment in terms of substantial removal of suspended solids, BOD5, fecal coliform, and nutrients such as N and P. The treatment process in CWs generates an effluent of better quality that can be applied on agricultural land or discharged to surface waters (CH2M Hill, 1997). Wastewater treatment in CWs occurs by a combination of mechanisms including biochemical conversions, settling/filtration, litter accumulation, and volatilization. Removal of pollutants in CWs is facilitated by shallow water depth (which maximizes the sediment-water interface), slow flow rate (which enhances settling), high productivity, and the presence of aerobic and anaerobic environments.

  A database, developed by CH2M Hill and Payne Engineering (1997), containing design, operational, and monitoring information from 48 livestock CW systems (in the United States and Canada), indicates that CWs have been, and continue to be, used successfully to treat animal waste including wastewater from dairy, cattle, swine, and poultry operations. The majority of CW sites included in the database have begun operations since 1992. Cattail, bulrush, and reed, in that order, dominate the aquatic vegetation planted in the surveyed CWs.

Typically, effluent from a CW treating animal waste is stored in a waste storage lagoon. Final dispersal occurs through irrigation to cropland and pastureland, though the potential for direct discharge of effluent exists. Direct discharge may, however, require a permit under USEPA's NPDES.

A performance summary of CWs used for treating animal waste indicates a substantial reduction of TSS (53 to 81 percent), fecal coliform (92 percent), BOD5 (59 to 80 percent), NH3-N (46 to 60 percent), and N (44 to 63 percent) for wastewater from cattle feeding, dairy, and swine operations (CH2M Hill and Payne Engineering, 1997). In a study by Hammer et al. (1993), swine effluent was treated in five CW cells, located below lagoons, that were equipped with piping that provided a control for variable application rates and water level control within each cell. Performance data indicate notable (70 to 90 percent) pollutant removal rates and reliable treatment of swine lagoon effluent to acceptable wastewater treatment standards for BOD5, TSS, N, and P during the first year of the reported study.

Removal efficiency of N is variable depending on the system design, retention time, and oxygen supply (Bastian and Hammer, 1993). Low availability of oxygen can limit nitrification, whereas a lack of a readily available carbon source may limit denitrification (Corbitt and Bowen, 1994). Fecal coliform levels are significantly reduced (>90 percent) by sedimentation, filtration, exposure to sunlight, and burial within sediments (Gersberg et al., 1990). Compared with dairy systems, higher reduction of pollutants have been reported for swine wastewater treatment in CWs, probably because loading rates have tended to be lower at swine operations (Cronk, 1996).

5.2.6 Waste Utilization

Ultimately, most animal waste will be applied to the land. The goals of land application should include optimal utilization of manure nutrients, reducing the movement of manure and constituents off-site, and preventing the delivery of polluted runoff to surface or ground waters.

- **Nutrient Management Planning.** Nutrient management is a planning tool farmers use to control the amount, source, placement, form, and timing of the application of nutrients and soil amendments (USDA NRCS, 1999). Planning is conducted at the farm level because nutrient requirements vary with such factors as the type of crop being planted, soil type, climate, and planting season. The primary objective of a nutrient management plan (NMP) is to balance nutrient availability with crop nutrient requirements over the course of the growing season. By accurately determining crop nutrient requirements, farmers are able to optimize crop growth rates and yields while reducing nutrient losses to the environment. Effective nutrient management requires a thorough analysis of all the major factors affecting field nutrient levels. CNMPs should address, as necessary, feed management, manure handling and storage, land application of manure, land management, record keeping, and other waste utilization options. While nutrients are often the major pollutants of concern, the plan should address risks from other pollutants, such as pathogens, to minimize water quality and public health impacts from animal feeding operations. Best management practices (BMPs) are also a part of a CNMP. BMPs may also include managing the farm to reduce soil erosion and improve soil tilth through conservation tillage, planting cover crops to catch excess nutrients or using filter strips and buffers to protect water quality.

For each field, the nutrient management plan within a CNMP should address these issues:

- **Soil testing** to establish existing levels of each nutrient as a basis for determining how much to be added;
- **Manure testing** to determine the actual nutrient content of manure and other organic residues used on the farm;
- **Yield goals** to determine total nutrient requirements and ensure utilization of nutrient supply;
- **Plant nutrient requirements** set according to plant growth requirements and yield goals;
- **Nutrient** budget for N, P, and K to consider all potential sources on the farm;
- Phosphorus management considerations to address excessive soil test P levels or areas at high risk for runoff losses;
- **Nitrogen** management considerations to adjust for previous crops and N availability; special considerations for sensitive areas, seasonal restrictions, irrigation management, or cover crops; and leaching concerns;
- Specifications of the **amount, form, timing, and methods of waste application**, including issues of equipment calibration and seasonal variations in crop need for nutrients; and
- **Record keeping** to monitor progress and track how the nutrient management plan is accomplishing its goals.

- **Amount, form, timing, and methods of waste application**. Decisions on the amount, form, timing, and method of waste application represent the implementation of a nutrient management plan.

  Determining Manure Application Rates and Land Requirements. Manure application rate should be determined based on efficient crop use of nutrients - balancing the amount of manure that can be applied to meet crop needs against potential nutrient losses from excessive amounts. Application rate should be tailored to provide adequate nutrient supply for crop needs without leaving large amounts that are vulnerable to runoff or leaching after harvest. This determination is based on soil testing, manure analysis, yield goals, and crop nutrient needs using the information developed in a nutrient budget analysis to compare crop nutrient requirements with the supply of nutrients already present in the soil and the quantity to be provided per unit volume of animal waste. Depending on the cropping system, different amounts of nutrients will be required for optimum production. This final analysis allows the operator to determine how much land acreage is required to apply the animal manure generated or, conversely, how much manure can be applied to the available acreage. Guidance on manure application rate calculations is available elsewhere (USEPA, 2002a). It should be emphasized that while manure application rate may be easily determined by soil and manure nutrient composition, as well as the nutrient requirements for the crop system, further consideration should be given to soil type and timing of application. Attention to these factors aids in determining which fields are most appropriate for manure application. Before applying manure, operators should consider the soil properties of each field. Coarse-textured soils (high sand content) accept higher liquid application rates without runoff because of their increased permeability; however, manure should be applied frequently and at low rates throughout the growing season because such soils have a low ability to hold nutrients, which creates a potential for nitrate leaching (NCSU, 1998). Fine-textured soils (high clay content) have slow water infiltration rates, and therefore application rates of manure should be limited to avoid runoff. Application on soils with high water tables should be limited to avoid nitrate leaching into ground water (Purdue University, 1994).

Application Timing. The longer manure remains in the soil before crops take up the nutrients, the more likely those nutrients will be lost through volatilization, denitrification, leaching, erosion, and surface runoff. Timing of application is extremely important. To minimize N losses, manure should be applied as near as possible to planting time or to the crop growth stage during which N is most needed.

The best time to apply manure may vary by regional differences in climate, crops grown, soils, and by specific site characteristics. Spring is often the best time for land application to conserve the greatest amount of nutrients. Available nutrients are used during the cropping season. However, wet field conditions may result in export by surface runoff or leaching and a greater potential for soil compaction. Fall application usually results in greater nutrient losses (25 to 50 percent total N loss, depending on soil type, climate, and crop) than spring application, especially when the manure is not incorporated into the soil (MWPS, 1993). These N losses are a result of NH3 volatilization and conversion to nitrate, which may be lost by denitrification and leaching. However, fall applications allow soil microorganisms time to more fully decompose manure and release previously unavailable nutrients for the following cropping season. Summer application is suitable for small-grain stubble, noncrop fields, or little-used pastures. Manure can also be applied effectively to pure grass stands or to old legume-grass mixtures, but not on young stands of legume forage. Winter is the least desirable application time, for both nutrient utilization and pollution prevention. Considerable research has demonstrated that runoff from manure application on frozen or snow covered ground has a high risk of water quality impact (Thompson et al., 1979; Moore and Madison, 1985; Clausen, 1990 and 1991; Melvin and Lorimor, 1996).

Application Methods. Manure can be handled as a liquid (less than 8 percent solids), semisolid or slurry (8 to 21 percent solids), or solid (greater than 21 percent solids). The overall farm management system determines the final form of the waste to be applied (MWPS, 1993). Liquid manure is applied to fields by means of tank wagons, drag-hose systems, or irrigation systems. Tank wagons can either broadcast manure (surface apply) or inject it into the soil. The method of injection, and the corresponding level of disturbance to the soil surface, is extremely variable. Liquid-based manure can also be pumped from a tanker or storage facility located adjacent to the field through a long flexible hose. This umbilical or drag-hose system is feasible for both broadcasting and injecting manure. Irrigation equipment applies liquid manure pumped directly from storage (usually lagoons). Wastewater and manure can be applied by means of sprinkler or surface (flood) irrigation. Solid manure is broadcast using box-type or open-tank spreaders. For all application methods, calibration of equipment is essential so that the desired application rate can be achieved.

Regardless of the equipment used for application, surface vs. subsurface application is a key issue. Surface application, or broadcasting, is defined as the application of manure to land without incorporation. Simply applying manure to the soil surface can lead to losses of most of the available N, depending on soil temperature and moisture. N is lost through volatilization of NH3 gas, denitrification of nitrates, and leaching. Application method has an enormous influence on potential N losses shown in the following Table:

Application Method	**Estimated Loss to the Atmosphere***
Broadcast without cultivation	10 - 25 %
Broadcast with cultivation	1 - 5 %
Injection	0 - 2 %
Sprinkler irrigation	35 - 60 %
*Values reflect total N loss under each application method. Al-Kaisi et al. 2004	

It should be noted that reductions in atmospheric losses of N by incorporation result in greater N remaining in the soil and thus a greater potential for leaching losses, especially later in the growing season. For this reason, changes in atmospheric losses due to application method must be accounted for in decisions about overall nutrient application rate.

Incorporation of waste may also reduce the availability of other manure components for transport in surface runoff. In reporting low microorganism losses from land receiving manure, Patni et al. (1985) attributed the low bacteria counts to the application of liquid manure that was plowed into the soil immediately after application. However, microorganisms on the soil surface are vulnerable to the lethal effects of sunlight and dessication and organism die-off may be enhanced by surface application (Crane et al. ,1983). Jamieson et al. (2002) reported mixed conclusions on the influence of application method on bacteria losses. Although manure injection has been reported to reduce surface losses of indicator organisms, subsurface injection may reduce manure contact with surface soils and tend to increase bacteria transport to tile drains or ground water

- **Transportation of waste off-site.** If there are more nutrients present in the waste generated at a AFO facility than can be used by the crops on the available land, it may be necessary to export manure to achieve a farm nutrient balance. In this case, or in the case where the operation has no available cropland, the waste must be transported off the site to an area where the manure nutrients can be utilized or otherwise managed properly. Waste collection systems that reduce water content will reduce the costs involved in transporting wastes.
- **Runoff control.** Fields where manure is applied should have an appropriate conservation management system in place to prevent nutrients from leaving the landscape. Conservation practices that reduce soil erosion and water runoff, including grassed waterways, sediment basins, and buffers can help to minimize the transport of nutrients, microorganisms, and other manure constituents off-site.
- **Soil erosion control.** Strategies that protect the soil surface against detachment by raindrop impact and runoff forces can also prevent movement of manure constituents. Keeping sufficient cover on the soil is a key factor in this strategy. However, it should be cautioned that practices like reduced tillage tend to keep applied manure at the soil surface where it is vulnerable to movement. Reduced tillage also promotes infiltration, which may tend to move soluble manure constituents toward groundwater.
- **Reducing transport with the field.** Transport of sediment and manure constituents within a field can be reduced by several practices, including the use of vegetative cover, crop residue, and barriers. Strips of permanent vegetation like contour strips slow runoff and trap sediment.
- **Vegetated Filter Strips to treat field runoff.** There have been numerous studies of the use of VFS located at the edge of a field to filter or infiltrate surface runoff from land receiving animal waste, including cropland (planted or fallow) and from grassland/pasture land. This application most often corresponds to NRCS practice standard 393 Filter Strip or 386 Field Border. There is a large body of published literature an enormous data base on VFS performance that includes studies ranging from small plots to fields to mathematical models (e.g., Thompson et al.,1975; Bingham et al., 1980; Dillaha et al., 1989; Lee et al.,1989; Chaubey et al., 1994 and 1995; Coyne et al.,1995 and 1998; Srivastava et al.,1996; Entry et al.,2000a and 2000b; Uusi-Kamppa et al., 2000; Sanderson et al., 2001)

  Data on VFS performance for field runoff show:
  - TSS removal of 80 to 90 percent in runoff from cultivated land; most occurs by settling in the upper end of the strip, or about the first 5 meters.
  - TP removal of about approximately 50 to 80 percent generally occurs in about the first 10 meters; particulate P is removed with sediment; removal of fine particulates and dissolved P is more problematic.
  - Soluble P removal of about 40 to 70 percent at best; performance is highly dependent on infiltration processes

- Bacteria removal is generally not very effective; bacteria levels in runoff from buffers seems to equilibrate to roughly 1055 organisms/100 ml regardless of environmental condition.

Major factors in VFS effectiveness are pollutant concentration in the entering runoff, settling, dilution, and infiltration. The effects of a VFS on pollutant concentrations appears to be independent of the ratio of source area to VFS width, that is, within limits of hydraulic overload, output concentrations from a VFS are essentially constant regardless of the size of the contributing area. However, mass reduction effects generally decrease with increasing source area size. As with VFS to treat concentrated sources, performance depends on sheet flow and is sensitive to hydraulic overload.

5.2.7 Tile Drainage

The presence of artificial subsurface drainage on agricultural fields can be a major influence on pollutant transport and delivery:

- Tile drains intercept infiltrating subsurface water, and the materials in that water, and provide rapid conveyance to surface waters;
- Drainage systems may function as a short-circuit, allowing water to bypass treatment functions of vegetated filter strips, riparian forest buffers, and other processes (Lowrance et al., 1984a; Dils and Heathwaite, 1999);
- By reducing saturation in upper soils, drainage may reduce surface runoff, potentially transferring a pollutant from overland flow to ground water; and
- Drainage affects the nitrification and denitrification cycle by creating or eliminating anaerobic soil conditions, affecting the proportion of highly mobile NO_3-N available for leaching (Smith and Evans, 1998).

Transport of liquid manure contaminants may lead to high levels of nutrients and pathogens in subsurface drains and subsequently into receiving water bodies. It was previously believed that because of the physical filtering capacity of the soil matrix, only dissolved constituents were likely to be transported in tile drainage. However, it is now recognized that preferential flow paths - macropores - in the upper soil horizons can easily transmit microorganisms and particulate matter to tile drains (Simard et al., 2000; Jamieson et al., 2002).

There is ample evidence in the literature that tile drainage significantly affects water quality. Lowrance et al. (1984b) noted that growing season concentrations of NO_3-N, Ca, Mg, K, and Cl were much higher in drainage water than in streamflow in a Georgia coastal plain watershed. Nitrate load per hectare was more than 60 times greater from artificially drained fields than from the watershed as a whole; ammonium N was about 70 percent higher in drain effluent than in streamflow on a per hectare basis. In Iowa corn land, Hallberg et al. (1986) reported that up to 40 percent of applied fertilizer N was lost in tile water. Xue et al. (1998) estimated that tile drainage contributed 70 percent of watershed dissolved P load from Illinois corn land. Hatfield et al. (1998) concluded that subsurface drainage was the primary flow path for agricultural chemicals (nitrate, atrazine, and metolachlor) in an Iowa watershed. Evans and

Owens (1972) and Dean and Foran (1992) reported the application of liquid manures to tile drained fields resulted in elevated levels of nutrients and bacteria compared to normal tile discharge from unmanured sites.

The N in fresh manure is primarily in the ammonia form and is mineralized and nitrified to nitrate which is subject to leaching. Tile drainage can be a major pathway for delivery of N to surface waters (Lowrance, 1984b; Hallberg et al., 1986; Hatfield et al., 1998). Fleming and Bradshaw (1992) reported maximum levels of 88.2 mg/l of NH_4-N, and 1020 mg/l TSS in tile discharges shortly after application of liquid manures which originally contained 149 mg/l NH_4-N. Patni et al. (1993) determined that about 30 percent of applied N was lost as nitrated in tile drains under no-till/conventional till corn plots in Ontario. Elevated NO_3-N concentrations in rivers in Illinois, Iowa, and Minnesota generally coincide with the geographical location of extensive drainage systems in these states and the time of greatest subsurface tile drainage (Antweiler et al., 1995). Export of nitrate in tile drainage can be important over the long-term. Randall (1998) observed that during dry years when tile drainage was inactive, high levels of residual NO_3-N accumulated in the upper soil profile. During subsequent wet years, drainage water contained NO_3-N levels two to four times higher than normal. Annual NO_3-N losses ranged from 79 to 149 kg N/ha.

High applications of manure can also elevate P discharge from tile drains (Hergert et al., 1981). About 40 percent of the P in dairy manure occurs in the organic form; organic P compounds are generally more water soluble than inorganic forms and are therefore subject to leaching (Gerritse and Zugec,1977; Barnett, 1994). Xue et al. (1998) reported average export of 0.4 kg/ha/yr from tile drainage under corn-soybean rotation in Illinois. In an agricultural watershed in the UK, Dills and Heathwaite (1999) observed that P concentrations in tile discharge were low (<0.1 mg P/L) during base flow, but peaked (>1 mg /L) rapidly during high discharge events. The authors noted that drainage systems transport P more rapidly than natural subsurface routes and reduce contact time between percolating water and soils, reducing opportunities for adsorption or transformation. In Illinois corn land, tile drainage was estimated to contribute 70 percent of the watershed dissolved P load (Xue et al., 1998). Simard et al. (2000) reviewed studies in Canada and the UK demonstrating the occurrence of preferential pathways of P transport through soil. If the store of soil P is coincident with preferential flow pathways (macropores or tile drainage), permanent grassland may be vulnerable to transfer large amounts of P through subsurface pathways. P transport through drainage may be particularly important after storm events that follow surface P inputs as fertilizer or manure.

Although microorganisms are ordinarily expected to be filtered out as water passes through the soil matrix, there is increasing evidence of transmission of bacteria from manure application by macropores. Significant amounts of bacteria can reach surface water by infiltrating through the soil and traveling through subsurface drains to receiving waters. Dean and Foran (1992) reported that liquid animal waste applied to Ontario fields rapidly penetrated the soil and contaminated field tile drainage. Eight of twelve manure spreading events resulted in water quality degradation within 20 minutes to 6 hours of manure application. Bacteria levels increased 30 to 725,000 fold within a few hours of application. McLellan et al. (1993) reported peak levels of *E. coli* of 5.3×10^4 organisms/100ml in tile discharges shortly after application of liquid animal waste which originally contained 7.0×10^6 organisms/100ml. Joy et al. (1998) reported that variations in liquid manure application rate had no effect on bacteria levels in tile drainage; the strongest association with bacteria levels was rainfall amount following manure application. A strong association was also observed between the presence of flow in tile lines prior to application and subsequent detection of bacteria in tile lines. Geohring et al. (1998) observed that pre-wetting tile drained plots enhanced transmission of bacteria from liquid manure applications to tile lines. Irrigation within a few hours of manure application resulted in peak fecal coliform levels of 1.1×10^5 organisms/100 ml, while irrigation 6 days after application yielded peak bacteria levels of 3.8×10^4 organisms/100 ml.

Overapplication of swine waste poses a threat to water quality through tile drainage. Cook and Baker (2001) reported that a high rate of waste application (830,000 L/ha) initiated flow and increased levels of N (3.4 - 9.9 mg NO_3-N/L), P (0.01 - 0.65 mg P/L), and bacteria 10^5 - 10^6 organisms/100 ml) within 1 hour after application, as well as throughout following 15 days. The time immediately following application of waste poses the greatest threat to the quality of subsurface drainage. Levels of contamination were generally higher during periods of heavy rainfall, especially for bacteria.

Because protozoans such as Cryptosporidium and Giardia are similar in size range (Pask, 1994), the occurrence of indicator bacteria in tile drainage may also indicate the presence of these pathogens. Jamison et al. (2002) documented field scale transport studies that have shown significant transport of bacteria to tile drains, primarily controlled by macropore flow phenomena. Preferential flow processes aid in rapid transport of bacteria from manure application. The authors proposed several management strategies to minimize leaching of microorganisms:

- Animal wastes should not be applied when tile drains are already flowing or within 72 hours of a runoff event;
- Subsurface injection may reduce runoff losses but may increase risk of bacterial movement in drainage water; and
- Disturbing top soil layer to break up macropores may reduce delivery of microorganisms to the tile drainage system.

Additional management practices that can be used to reduce pollution through tile drainage include;

- Plugging the drainage lines and allowing them to be filled with water prior to land application of waste to prevent the direct entry of the wastewater into the lines,
- Avoid spreading the waste directly over the drainage lines.

5.3 Costs and Applicability

5.3.1 Overview

The costs and benefits of practices and strategies to protect the environment vary across animal types, facility sizes, waste management handling systems, and local site conditions (including climate and availability of land upon which manure can be spread). The applicability of these practices and strategies is also largely site specific, particularly when considering the type and degree of management required to implement them.

Costs and benefits can be estimated and represented in a number of ways, with unit costs and case-study or model farm costs being two of the more common approaches. Unit costs are useful in developing cost estimates for specific facilities, but can be misleading in the absence of facility-level applications. As discussed in this document, animal waste management systems typically integrate many specific practices and strategies, with each single practice affecting the cost and effectiveness of the other practices. For example, waste storage requirements are affected by the collection and pre-storage practices employed at the site. The absence of a settling basin will affect both the management and size of the storage structure used. Similarly, hauling and nutrient application are both part of and affected by the nutrient management program implemented at the site. Depending upon pre-existing farm management, local constraints (e.g., N-based or P-based nutrient management), and factors such as the availability of land to which manure can be applied, the implementation of a nutrient management program could reduce both fertilizer and hauling costs (e.g., more of the manure is spread on site), increase both fertilizer and hauling costs (e.g., supplemental N needed in a P-based management scenario that increases hauling), or have a mixed impact on costs and benefits (e.g., hauling is slightly reduced but supplemental N is needed).

Because of the interplay among practices and strategies implemented at animal feeding operations, costs in this report are summarized at the farm level (model farm) wherever possible. These costs are based primarily upon the methodology and results from the cost analysis performed in support of USEPA's revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations (CAFOs) (USEPA, 2002). Ten regulatory options were considered by USEPA, but costs in this report are taken from Option 1, except in cases where specific practice costs were needed from other cost options (e.g., anaerobic digesters for methane production and recovery under option 6 only for large dairies and large swine only).

For proper context, it is important to note the following constraints applied in estimating costs for Option 1:

> *Zero discharge from a facility designed, maintained, and operated to hold manure, litter, and other process wastewater, including direct precipitation and runoff from a 25-year, 24-hour rainfall event. This option includes implementation of feedlot best management practices, including stormwater diversions; lagoon and pond depth markers; periodic inspections; nitrogen-based agronomic application rates; elimination of manure application within 100 feet of any surface water, tile drain inlet, or sinkhole; mortality handling, nutrient management planning, and record-keeping guidelines.*

Cost summaries contained in this report cover the full range of facility types and sizes assessed in USEPA's CAFO analysis (USEPA, 2002). Facility types covered are beef feedlots, dairies (flush and hose-based systems), heifers, veal, broilers, dry layers, wet layers, swine farrow-to-finish and grow-finish (both with liquid, evaporative pond, and pit systems), and turkeys. Facility sizes are summarized in Table 5-2. USEPA's cost analysis used model farms to represent each animal type and size category subject to the proposed CAFO rule revision, and the facility cost data presented in this report apply to those model farms.

Table 5-2. Facility Sizes Used in Cost Analysis for CAFO Rule (USEPA, 2002)

Animal Type	Medium 1	Medium 2	Medium 3	Large 1	Large 2
Beef	300-499	500-749	750-999	1,000-7,999	≥8,000
Heifer	300-499	500-749	750-999	>1,000	N/A
Dairy (Mature Dairy Cows)	200-349	350-524	525-699	>700	N/A
Veal	300-499	500-749	≥750	N/A	N/A
Swine	750-1,249	1,250-1,874	1,875-2,499	2,500-4,999	>5,000
Dry Layers	25,000-49,999	50,000-74,999	75,000-81,999	82,000-599,999	>600,000
Wet Layers	N/A	N/A	9,000-29,999	>30,000	N/A
Broilers	37,750-49,999	50,000-74,999	75,000-124,999	125,000-179,999	>180,000
Turkeys	16,500-27,499	27,500-41,249	41,250-54,999	>55,000	N/A
N/A - Not applicable.					

The availability of cropland at AFOs was also considered in USEPA's CAFO analysis, with the following three categories used to characterize the range of on-site cropland availability at model farms:

Category 1: Facility has the acreage needed to apply agronomically the nutrients in manure generated at the facility using regional estimates of crop uptake and yield goals. This acreage does not include the area of the buffer strip.

Category 2: Facility has land, but not enough to apply agronomically the nutrients in manure generated at the facility.

Category 3: Facility has no land.

Because the constraints imposed in USEPA's cost analysis for the CAFO rule have varying effects due to the range of facility types, facility sizes, and available cropland acreages, cost ranges (1997 dollars, rounded) are provided wherever possible in this report, with zero costs typically reflecting either an absence of cropland at a facility (e.g., buffers for Category 3 facilities) or sufficient cropland to handle all manure on site (e.g., hauling for Category 1 facilities). All costs contained herein, however, represent “solutions” to the constraints imposed by Option 1.

5.3.2 Practices

5.3.2.1 Feeding Strategies

Feeding strategies that reduce nutrient concentrations in waste have been developed for specific animal sectors, and the costs of strategies for the swine and poultry industries are described below. Application of these types of feeding strategies to the beef industry has lagged behind other livestock sectors, so costs are not given here.

Feeding strategy costs for both swine and poultry are provided in Table 5-3. USEPA assumed in its cost model that phosphorus feeding strategy costs for broilers and layers are zero since integrators supply the feed to the growers (USEPA, 2002).

Table 5-3. Feeding Strategy Costs for Swine and Poultry (Tetra Tech, 2000)

Animal	Feeding Strategy Costs ($ Per Animal)	
	N Strategy	P Strategy
Broiler	0.055	0
Layer	0.3025	0
Turkey	0.23	0.023
Pig - Farrow to Finish	2.70	0.36
Pig - Grow Finish	2.70	0.36

Feeding strategy implementation affects hauling costs because the nutrient content of manure is changed. The examples in Table 5-4 showing changes to hauling costs at Category 2 farrow-to-finish swine operations due to the implementation of feeding strategies under N-based nutrient management were generated using USEPA’s CAFO cost model. In some cases, the feeding strategy cost exceeds the hauling cost savings; it must be noted that the net cost of implementing feeding strategies will depend upon a number of factors, including hauling distances, fuel and feed supplement prices, and nutrient management constraints (e.g., N-based or P-based).

Table 5-4. Savings in Hauling Costs at Farrow-to-Finish Swine Operations Due to Feeding Strategy Implementation

Number of Head	Annual Feeding Strategy Cost ($)	Cost to Haul Waste		Savings in Annual Hauling Cost ($)	Hauling Cost Savings minus Feeding Strategy Cost[1] ($)
		Without Feeding Strategies ($)	With Feeding Strategies ($)		
12,132	$68,800	$370,200	$270,500	$99,700	$30,900
11,059	$62,700	$282,100	$224,700	$57,400	($5,300)
3,694	$20,900	$94,200	$75,100	$19,200	($1,800)
3,457	$19,600	$109,700	$82,400	$27,300	$7,700
2,035	$11,500	$22,900	$0	$22,900	$11,300
1,465	$8,300	$16,500	$0	$16,500	$8,200
952	$5,400	$3,700	$0	$3,700	($1,700)

[1]Other additional costs and/or savings (e.g., reduced storage) may also apply.

5.3.2.2 Nutrient Management Planning

Nutrient management involves capital costs, annual costs, and less frequent recurring costs (e.g., once per three or five years). The range of capital costs for nitrogen-based nutrient management at beef feedlots, dairies, heifer and veal operations is shown in Figure 5-6 (USEPA, 2002). With the exception of large beef operations, capital costs are typically below about $4,000. Annual costs for these same operations run from a low of about $1,200 to a high of about $18,000, with the annual cost for most medium-size operation between $1,000 and $2,000. Three-year recurring costs are typically $20-$500, with a maximum of about $4,500 at the largest beef feedlots. Costs are higher at the largest beef operations because they are far larger than other operation types.

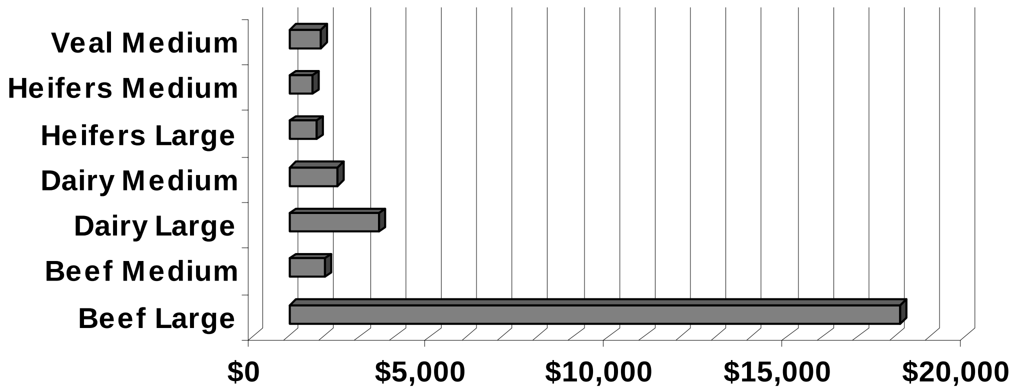

Figure 5- 6. Capital Costs of Nitrogen-Based Nutrient Management at Dairy, Beef, Veal and Heifer Operations

5.3.2.3 Litter Storage Sheds

Litter storage was included for dry poultry operations only in USEPA's CAFO cost analysis (USEPA, 2002). Poultry litter storage structures include a roof, foundation and floor, and suitable building materials for side walls. Storage for six months was assumed in USEPA's analysis, and a construction cost of $8.50 per square foot was used. Figure 5-7 summarizes the cost estimates for litter storage sheds at dry poultry operations (USEPA, 2002).

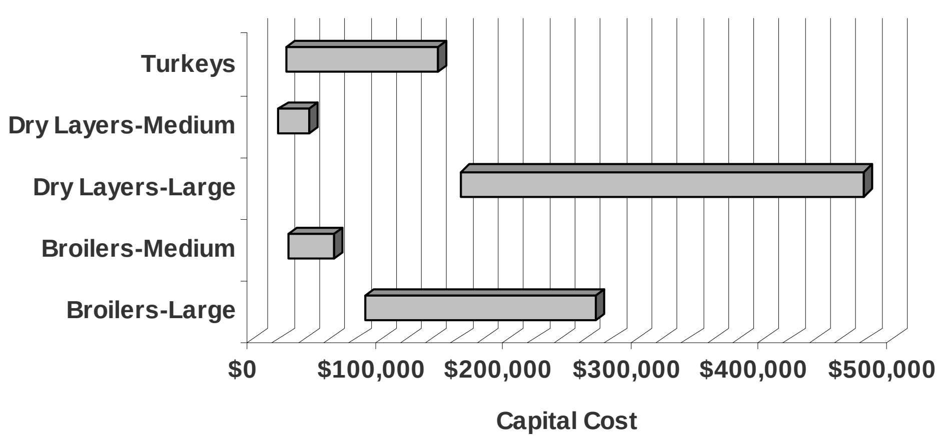

Figure 5- 7. Costs of Litter Storage Sheds for Dry Poultry Operations

5.3.2.4 Lagoon Storage and Liners

Anaerobic lagoons are used at dairy, veal, wet layer, and swine operations to collect process water and flush water containing manure waste. USEPA's cost model for the CAFO rule assumed that all dairies and veal operations use anaerobic lagoons, some swine and poultry operations require a lagoon, and beef feedlot and heifer operations use a storage pond (see *Storage Ponds*). The cost model also assumed that swine operations use either pit, anaerobic lagoon, or evaporative pond systems, while all wet layer operations use anaerobic lagoons. Broiler, turkey, and dry layer operations were assumed to not use anaerobic lagoons (USEPA, 2002).

At dairies, all of the manure and wastewater that is flushed or hosed from the dairy parlor or barn is washed to a concrete settling basin (see *Settling Basins*) or separator before it enters a lagoon. Costs for naturally-lined lagoons with 180 days of storage were developed for dairies and veal operations (USEPA, 2002). In addition, costs were also estimated for lagoons with synthetic liners for ground-water protection. Synthetic liner systems consist of clay soil with a synthetic liner cover. The liner dimensions are equal to the surface area of the floor and sides of the lagoon. The cost for the clay is assumed to be 24 cents per square foot, whereas the cost of a synthetic liner is $1.50 per square foot. Figure 3 shows cost ranges for naturally-lined and synthetically-lined lagoons for dairy and veal operations (USEPA, 2002).

In USEPA's cost model, lagoons were assumed as part of the baseline scenario for wet layer operations and some swine operations with liquid-based systems (USEPA, 2002). Other swine operations were assumed to have pit storage or evaporative pond systems under baseline conditions, and all other poultry operations were assumed to use solid-based manure management systems. Thus, lagoon construction costs for swine and poultry model farms were estimated by USEPA (USEPA, 2002). The cost of extra lagoon capacity was estimated, however. The capital cost equation for such capacity incorporates an excavation cost of $2.60 per cubic yard, an excavation volume based on the quantity of waste to be stored, and a liner cost. Liner costs were assumed to be the same as those used for dairies and veal operations. The capital cost for lagoons at swine and wet layer operations is calculated as follows:

$$\text{Capital Cost} = \text{Excavation Cost} \times \text{Volume Excavated} + \text{Liner Cost}$$

5.3.2.5 Storage Ponds

As noted above under *Lagoon Storage and Liners*, USEPA's cost model for the CAFO rule assumed that beef feedlot and heifer operations use a storage pond (USEPA, 2002). Waste storage ponds are used to contain wastewater and runoff from contaminated areas (e.g., barnyard). Manure and runoff are routed to the storage pond where the mixture is held until it can be used for irrigation or can be transported elsewhere. Solids settle to the bottom of the pond as sludge, which is periodically removed and land applied on site or off site. USEPA's cost model assumed that only direct precipitation or runoff that has gone through a settling basin (or separator) enters the storage pond. Figure 5-8 shows cost ranges for naturally-lined and synthetically-lined storage ponds for dairy and veal operations and Figure 5-9 presents the same information for beef feedlots and heifer operations (USEPA, 2002). Liner costs were determined in the same manner as liners for lagoons.

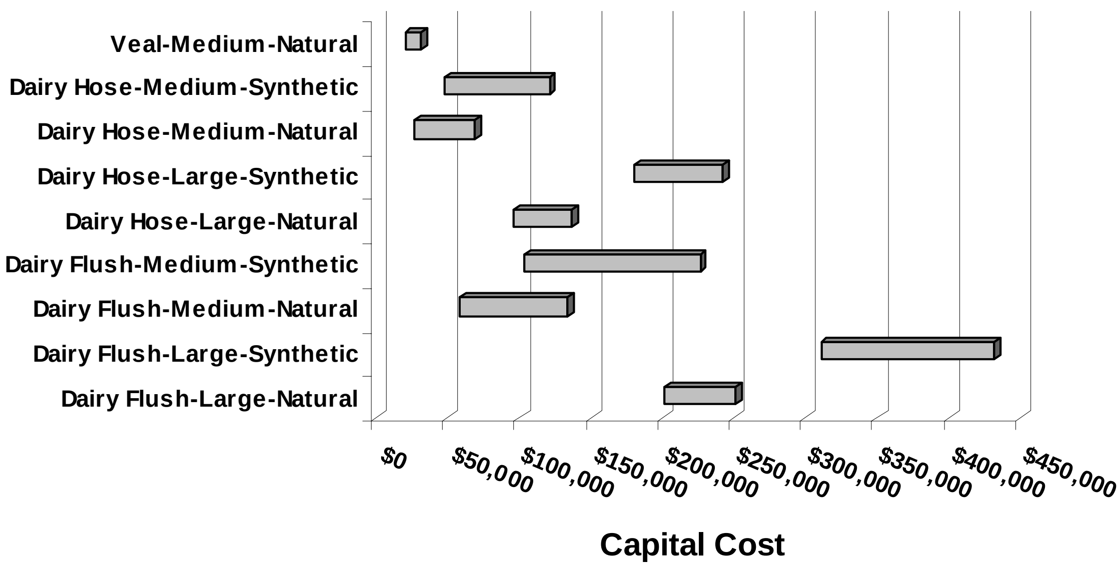

Figure 5-8. Capital Cost of Naturally-Lined and Synthetically-Lined Lagoons at Dairy and Veal Operations

5.3.2.6 Settling Basins

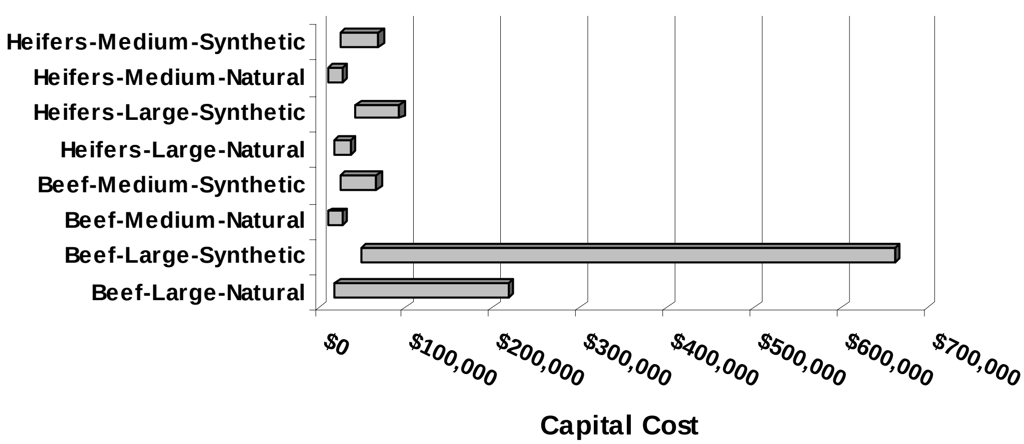

Figure 5- 9. Capital Costs of Naturally-Lined and Synthetically-Lined Ponds at Beef and Heifer Operations

Settling basins are shallow basins designed to remove manure solids, soil, and other solid materials from wastewater prior to storage in a pond or further treatment (e.g., a lagoon). USEPA's cost model assumed that earthen settling basins would be used at beef and heifer operations, whereas concrete settling basins would be used at dairy operations. Dairy operations require more structurally sound concrete rather than earthen basins to handle the higher wastewater flows from the barns and milking parlors. Veal operations were also assumed to have concrete settling basins, while settling basins were not used at swine and poultry operations. Costs are summarized in Figure 5-10 and Figure 5-11, derived from USEPA's cost analysis for the CAFO rule (USEPA, 2002). Periodic removal of settled solids is factored into the annual

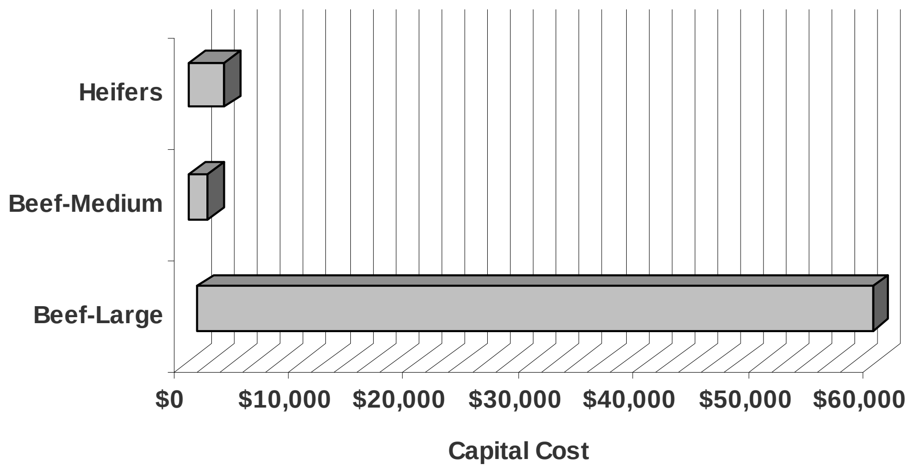

Figure 5- 10. Costs of Earthen Settling Basins at Beef and Heifer Operations

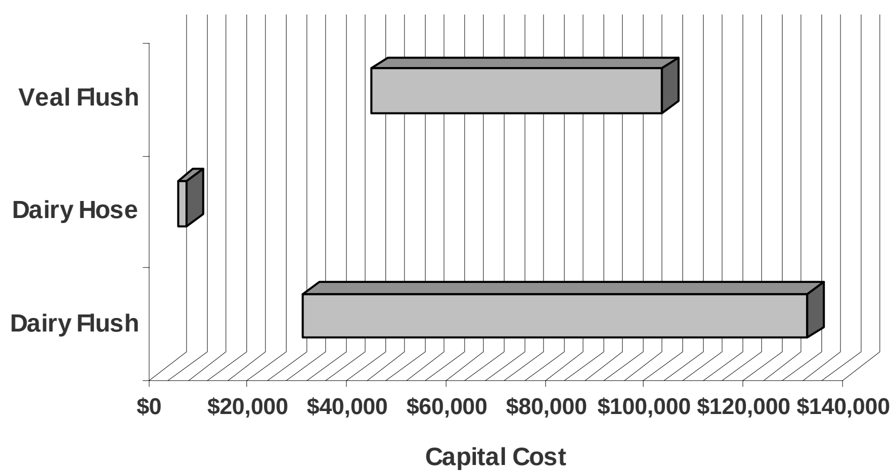

Figure 5- 11. Costs of Concrete Separators at Dairy and Veal Operations

costs for earthen settling basins, which range from about $20 to $200 for heifers and medium-sized beef feedlots, and from $50 to $3,000 for large beef feedlots. The annual costs for concrete separators at all dairy and veal operations assessed range from about $70 to $3,000.

5.3.2.7Mechanical Solid-liquid Separation

Solid-liquid separation is the partial removal of organic and inorganic solids from a mixture of animal wastes and process-generated wastewater to make the liquids easier to pump and handle. USEPA's cost model for the CAFO rule estimated costs to swine operations for screen separation. As the liquids pass through the screen, the solids accumulate, and are eventually collected. After collection, the solids may be handled more economically for hauling, composting, or generating biogas (methane).

Costs for solid/liquid separation include a tank with sufficient capacity to store solids for six months, a mechanical solids separator, piping, and labor for installation. USEPA estimated that the cost of installing a steel storage tank was $0.18/gallon (USEPA, 2002). The cost of a separation device was estimated at $13,000 for medium-sized operations and $28,000 for large operations, (USDA NRCS, 2002). The annual cost of operation and maintenance of solid-liquid separation systems was estimated by USEPA to be 2 percent of the total cost of installing the system (USEPA, 2002). USEPA's CAFO cost model was used to generate the Figure 5-12 cost estimates for installing and setting up separators and storage at Category 2 and 3 farrow-to-finish swine operations.

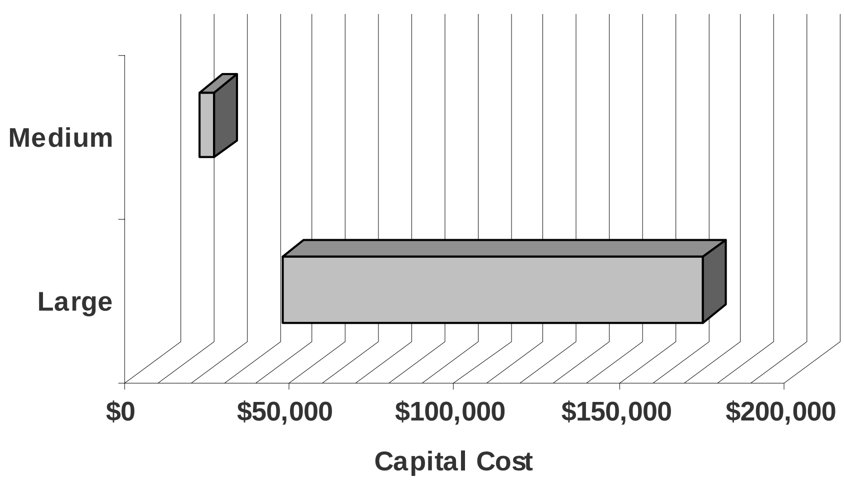

Figure 5- 12. Costs of Separators for Category 2 and 3 Farrow-to-Finish Swine Operations

5.3.2.8 Anaerobic Digesters for Methane Production and Recovery

Anaerobic digesters are sometimes used at AFOs to biologically decompose manure while controlling odor and extracting biogas for energy generation. Depending on the waste characteristics, one of the following main types of anaerobic digesters may be used: plug flow, complete mix, and covered lagoon. To estimate the costs for a digester system, dairies that operate flush cleaning systems were assumed to use a covered lagoon system following a settling basin, while dairies that operate scrape (hose) systems were assumed to use a complete mix digester following a settling basin (USEPA, 2002). In USEPA's CAFO cost analysis, the design of the digester and methane recovery system for dairies were based on the AgSTAR FarmWare model (USEPA, 1997). FarmWare costs include the digester and energy recovery equipment. Settling basin costs were determined separately (see *Settling Basins*) and are not reflected in the costs for dairies in Table 4 (USEPA, 2002). FarmWare estimates annual costs include operating savings, water costs for dilution water, and an estimated 15 percent of the total capital costs. The cost of digesters for swine operations was estimated using the following equation:

$$\text{Capital Cost} = \text{nohead} \times \text{capheadcost}$$
$$\text{Annual Cost} = \text{nohead} \times \text{annheadcost}$$

where:
Nohead = Number of animals
Capheadcost = Capital cost per animal
Annheadcost = Annual cost per animal.

Capital costs for swine operations ranged from \$33.81 per head to \$42.10 per head, and annual costs ranged from -\$6.31 per head to -\$1.97 per head (USEPA, 2002). Table 5-5 summarizes the estimated costs of anaerobic digesters and ponds for large dairies and large swine operations as an alternative to anaerobic lagoons (USEPA, 2002).

Table 5-5. Costs for Anaerobic Digesters for Large Dairy and Swine Operations

Animal	Size	Low-End Cost		High-End Cost	
		Capital	Annual	Capital	Annual
Dairy Flush	Large 1	$214,400	($42,100)	$214,400	($42,100)
Dairy Hose	Large 1	$377,400	($45,600)	$377,400	($45,600)
Swine Farrow to Finish	Large 2	$206,200	($12,600)	$1,181,500	($74,400)
	Large 1	$84,500	($5,300)	$179,600	($11,000)
Swine Grow-Finish	Large 2	$233,800	($33,000)	$1,314,600	($193,900)
	Large 1	$94,000	($13,900)	$192,000	($26,300)
Values in parentheses are negative values denoting income.					

5.3.2.9 Aerobic Treatment of Liquids

Aeration of a manure slurry provides odor control because aerobic decomposition of organic matter does not create malodorous compounds as byproducts (Baumgartner, 1998). Aeration, however, requires substantial energy to provide sufficient oxygen to satisfy the biochemical oxygen demand of a manure slurry. Costs range from $2 to $6 per finished pig.

5.3.2.10 Composting

USEPA's cost model for the CAFO rule assumed that windrow composting was used at beef feedlots, heifer operations, and dairies (USEPA, 2002). Capital costs for windrow composting included turning equipment and thermometers, while annual costs covered labor, any necessary composting amendments, and the sale of finished product. USEPA assumed that beef feedlots and heifer operations could compost the manure collected from the drylots, but that the waste generated at dairies and veal operations using flush and hose systems was too wet for composting. It was assumed, however, that the manure from calves and heifers kept on drylots at dairies was composted, as were separated solids from sedimentation basins. Nonetheless, the annual composting costs for dairy operations are far lower than those for beef operations because the wet manure is not included in the analysis. The capital cost of windrow composting at dairies, beef, and heifer operations was about $9,200 for all operations. Figure 5-13 shows the range of annual costs, with the exception of large beef operations which incur an annual cost ranging from about $50,000 to $1 million.

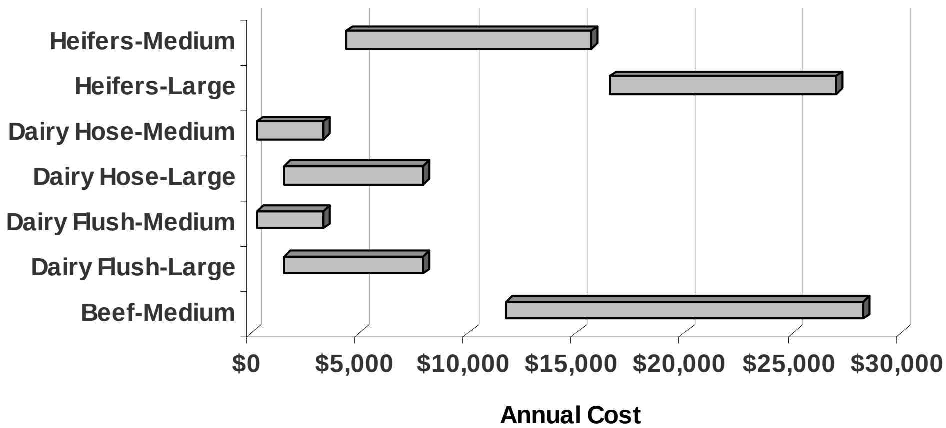

Figure 5-13. Annual Costs of Composting Manure at Beef, Dairy, and Heifer Operations

USEPA also estimated the cost of mortality composting facilities for all swine and poultry operations (USEPA, 2002). Capital costs for the mortality composting facility were estimated assuming a stacking depth of 5 feet and a construction cost of $7.50 per square foot. Annual costs covered labor, tractor usage, composting amendments, and the sale of finished compost. The capital cost estimates for mortality composting at swine operations shown in Figure 5-14 were generated using USEPA's CAFO cost model. Annual costs ranged from about $3,600 to $3,750 for swine facilities. Capital costs for mortality composting facilities are greatest at broiler operations on a per head basis ($0.1125/head), followed by turkey operations ($0.0761/head) and dry and wet layer operations ($0.0286/head). Annual costs at poultry operations ranged from

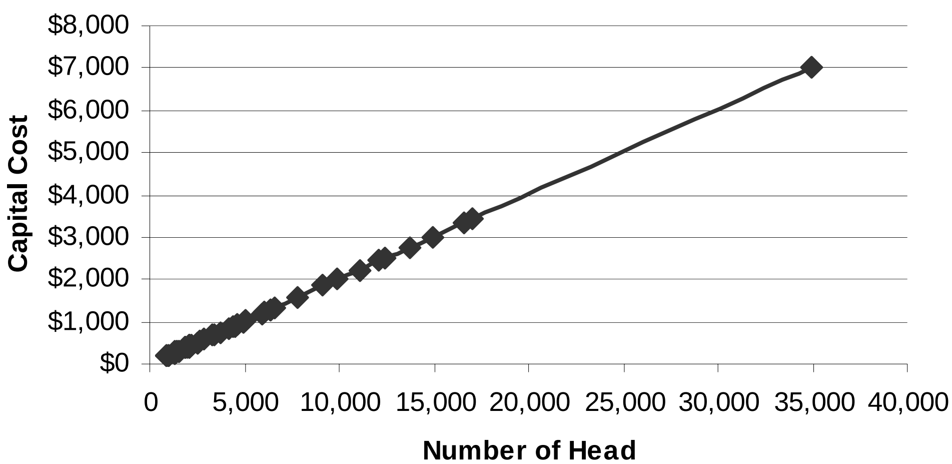

Figure 5-14. Mortality Composting Costs at Swine Operations

about $3,600 to $4,300.

5.3.2.11 Vegetated Filter Strips

The design and installation of a grass filter strip 1,000 feet long and 66 feet wide is estimated to cost $129 (USEPA, 1993). In 1997 dollars, the cost would be about $144 (Sahr, 2004).

5.3.2.12 Runoff control

Berms are earthen structures that divert clean runoff away from pollutant sources and channel runoff that falls within the area containing pollutant sources (e.g., feedlots) to ponds or lagoons.

In generating cost estimates for the CAFO rule, USEPA assumed that berms were constructed around handling and feeding areas at all beef feedlots, heifer operations, and dairies (USEPA, 2002). At poultry and swine operations, berms were assumed to consist of two adjacent sides up-gradient

from storage facilities or lagoons. Swine operations with pit storage were assumed to not need berms because the animals and manure are inside, and USEPA assumed that veal operations were indoors as well. Figure 5-15 summarizes capital costs for those operations needing berms (USEPA, 2002). Annual costs range from about $10 to $100 for all but the very large beef feedlots.

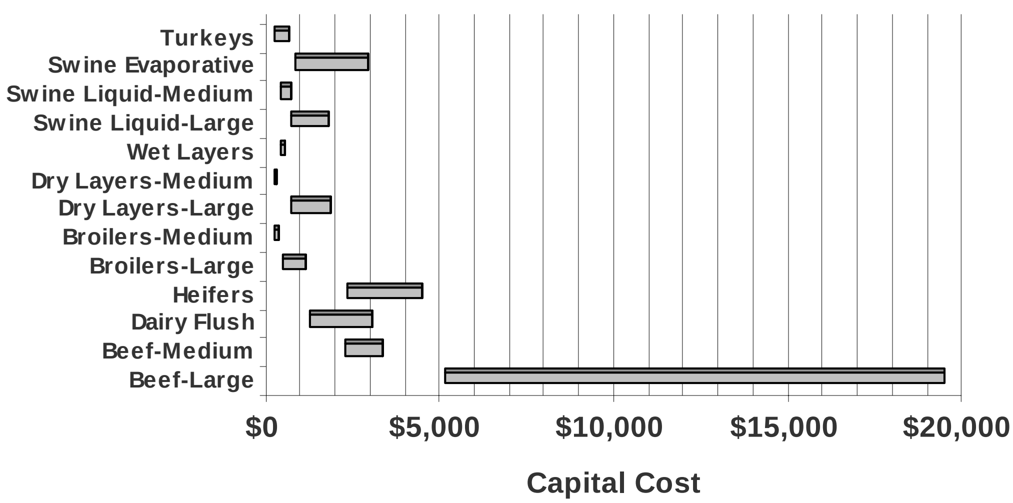

Figure 5- 15. Cost of Berms at All Animal Operation Types

5.3.2.13 Streamside Buffers

The range of estimated costs of 100-foot wide buffer strips for swine and poultry operations is shown in Figure 5-16 (USEPA, 2002). Such buffer strips would be established for streamside fields receiving manure applications. Zero values reflect the fact that some operations do not have fields adjacent to streams. Buffer strip cost was estimated as $3.72 per acre of total cropland (USEPA, 2002). Annual costs range from $0 to about $11,000 for the largest dry layer operations, with the typical range being $0 to about $2,000 for poultry operations and $0 to $900 for swine operations.

5.3.2.14 Retrofit of Wet Flush Systems to Dry Scrape Systems

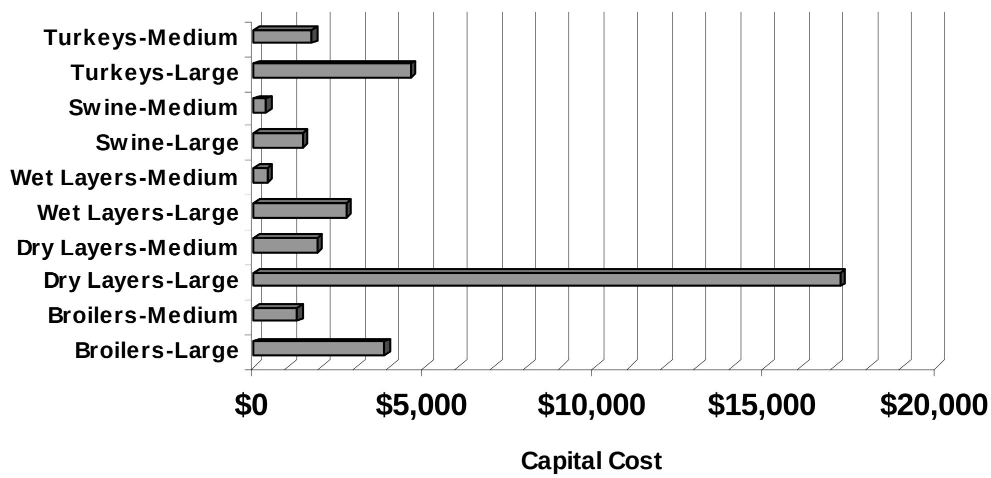

Figure 5- 16. Capital Costs of Buffers at Poultry and Swine Operations

When facilities are retrofitted to a scraper system, undiluted manure is scraped and moved to a covered steel tank to limit dilution by rain. The cost of scraper systems was estimated for both swine and wet-layer facilities in USEPA's cost model for the CAFO rule (USEPA, 2002). It was assumed that one retrofit unit was required for each 1,250 hogs or 25,000 layers. Initial costs include the retrofit setup ($36,000), motor ($200), blades (4 steel blades at a total cost of $708), steel tank ($0.18 per gallon), and closure of the old lagoon. Annual operation and maintenance include labor, electricity, replacement blades and standard maintenance estimated at two percent of initial costs.

USEPA's CAFO cost model was used to generate the Figure 5-17 cost estimates for retrofitting liquid swine operations to scraper systems. Annual costs ranged from about $3,000 to $45,000.

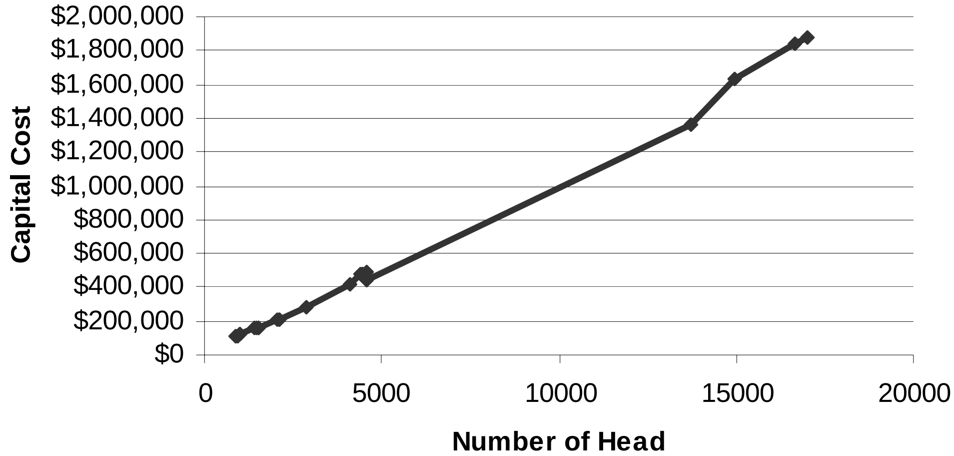

Figure 5- 17. Cost of Retrofitting Liquid Swine Operations to Scraper Systems

5.3.2.15 *Hauling/Transport off Site*

Hauling costs depend upon a number of factors, including the nutrient management basis (N- or P-based, where P-based management requires more land), feed management, the form of the waste (solid or liquid), fuel prices, and the distance to off-site fields capable of receiving a facility's excess waste. In the CAFO cost analysis, USEPA estimated the costs associated with transporting excess waste off site using two methods: contract hauling of the waste and the purchase of transportation equipment (USEPA, 2002). Hauling at swine and poultry operations was assumed to be accomplished via contract hauling.

Under contract hauling, the operation hires an outside firm to transport the excess waste. In determining costs for the contract-hauling option, USEPA's CAFO cost model considered three major factors:

1) Amount of waste transported;
2) Type of waste transported (semisolid or liquid); and
3) Location of the operation.

Additional factors that relate to these three major factors include:

4) Hauling distance;
5) Weight of the waste; and
6) Rate charged to haul waste.

USEPA estimated the hauling rates for liquid and solid wastes for Category 2 and 3 beef feedlots and dairies shown in Table 5-6 based on information obtained from various contract haulers (USEPA, 2002). Because Category 3 operations have no land, USEPA assumed that they were already hauling waste under an N-based nutrient management scenario. Hauling costs for these facilities were therefore assumed to be zero (i.e., no increase). The hauling rates USEPA used for swine and poultry operations are presented in Table 5-7 (USEPA, 2002).

USEPA's other cost method involved the purchase of transportation equipment. In this method, the operation owner purchases the necessary trucks to haul the waste to an off-site location. Depending on the type of waste transported, a solid waste truck, a liquid tanker truck, or both types of trucks are required. In addition, the owner is responsible for determining a suitable location for the waste, as well as all costs associated with loading and unloading the trucks, driving the trucks to the off-site location, and maintaining the trucks. A detailed description of the cost considerations made under this method can be found in USEPA's cost analysis for the CAFO rule (USEPA, 2002).

Table 5-6. Rates for Contract Hauling for Category 2 and 3 Beef Feedlots and Dairies

Type of Waste	Category 2 Rates ($/ton-mile)		Category 3 Rates ($/ton-mile)	
	N-Based Application	P-Based Application	N-Based Application	P-Based Application
Solid	0.24	0.15	0	0.08
Liquid	0.53	0.10	0	0.26

Table 5-7. Hauling Rates for Category 2 and 3 Swine and Poultry Operations

Type of Waste	Rate
Liquid-First Mile	0.008 $/gallon-mile
Liquid-Beyond First Mile	0.0013 $/gallon-mile
Solid-Less than 90 Miles	0.10 $/ton-mile
Solid-90 to 1230 Miles	0.23 $/ton-mile
Solid-Beyond 1230 Miles	0.18 $/ton-mile

5.4 BMP Selection Factors

The selection of a practice or set of practices to protect water quality is often site-specific and should be based on a number of factors that exist at a particular AFO:

5.4.1 Contaminant(s) to be Controlled

A BMP to protect water quality must be effective in the control of the contaminant(s) that threaten water quality. Issues to consider include:

Dissolved vs. particulate. Pollutants such as nitrate or dissolved P move with water and need to be addressed with practices that control water movement. Pollutants that exist mostly in the particulate form like sediment and P or chemicals that are bound to soil particles need to be controlled by erosion control BMPs.

Solubility/mobility. Pollutants that are strongly adsorbed to soil particles (like P) or that may be filtered out with movement through the soil (like microorganisms) require different management from pollutants like nitrate that move freely through the soil.

Volatility. Pollutants such as ammonia N that are easily volatilized from surface applications of animal waste need specific practices to reduce losses of fertilizer value, odor problems, and transport of N off-site.

Multi-media. BMPs should be selected to avoid shifting a pollutant from one medium to another or adding a new pollutant. Ammonia volatilization from surface applied manure can be reduced by soil incorporation after application or by subsurface application techniques. However, incorporation can increase soil erosion. Manure collection, transfers, and storage may require special measures to reduce losses of ammonia and other chemicals to the atmosphere. Additions of combustion byproducts or alum to animal waste to change solubility characteristics may end up adding toxic heavy metals to agricultural soils. Technical specifications of many USDA NRCS BMPs include information on what pollutants each practice is intended to control (USDA NRCS, 2004b).

5.4.2 Transport factors

Many BMPs function to interrupt the transport of pollutants away from their source toward receiving water. Therefore, it is critical to understand how the pollutants are transported in order to select an appropriate BMP. Sediment-bound pollutants, for example, are often addressed with practices that deal with the erosion process, such as maintaining surface cover, reducing slope-length, or controlling overland flow. Practices like cover crops, catch crops, and riparian buffers are more appropriate to capture soluble pollutants moving with infiltrating water. Buffer strips may serve both functions by settling and filtering sediments and by nutrient uptake from growing vegetation.

5.4.3 Cost/effectiveness

Although not all BMPs require major capital investment, the cost of practices and the ability of the producer to bear those costs will affect BMP selection. Effectiveness of practices in relation to cost is also an important selection criterion.

5.4.4 Site conditions

Site conditions on the farm affect BMP selection. Factors like soil erodibility, leaching potential, topography, proximity to water, and climate place constraints on what BMPs are required and on the specific design of practices.

5.4.5 Farm operations

The characteristics of the agricultural operation itself are critical considerations in selection of appropriate practices. Nutrient management practices will differ markedly, for example, between a large confinement AFO and a small dairy farm. On a large AFO, crop nutrient needs are supplied by purchased fertilizer and animal waste and can be applied by precision farming methods according to soil and crop testing. In contrast, crop nutrient needs on a small dairy farm are supplied by animal waste and legume rotations, as well as by purchased fertilizer, and exact nutrient balance is often difficult to achieve. The equipment and facilities available to the producer, such as manure or fertilizer application equipment and the type of waste storage system influence both the nature of the organic materials to be used in nutrient management and the producer's ability to efficiently manage nutrient resources. The availability of an adequate land base to accept manure nutrients may be a critical determinant of what BMPs can be applied.

5.4.6 Resources available

Availability of technical assistance is another determinant of BMP selection, particularly in regions dominated by animal agriculture where producers have been more likely to focus on herd management than crop management. State Land Grant Universities, Cooperative Extension, and producers' organizations are important resources. The ability of a producer to employ sophisticated soil or plant testing may depend on the availability of qualified crop management services or consultants. The availability of innovative soil and plant tissue testing or manure processing procedures from Agricultural Experiment Stations or research facilities can support development of sophisticated nutrient management programs. Federal or state regulations and incentives may specify or promote a range of BMPs that may be used or even set out requirements for specific practices. The Final CAFO rule, for example (USEPA 2003) requires the preparation of a CNMP with particular features. State nutrient management programs such as those in Pennsylvania (PA Nutrient Management Program 2004) and Maryland (Maryland Water Quality Improvement Act, 2004) place some specific requirements on nutrient management, including record-keeping and reporting. Federal and state incentive programs offering cost-share and technical assistance may allow for increased use of specific types of BMPs. However, BMPs should be selected for their own merit, and agricultural management programs should be structured to allow and follow these selections. Selecting BMPs because they are cost shared may result in poor and inefficient environmental protection. Several other broad issues should be factored into the selection of practices to protect water quality.

Targeting. Not all land or all parts of an AFO contribute pollutants equally. Within a watershed, BMPs should be targeted to areas that are likely to contribute more pollutants. Similarly, parts of a farm that are more at risk to contribute the greatest pollutant loads should be targeted for protection (Gale et al., 1993). Examples include areas of high soil P and high runoff potential or areas of highly erodible soil.

Priorities. Animal wastes can potentially contribute a number of different pollutants that threaten water quality. Within critical target areas, pollutants and sources should be prioritized based on expected impacts on water quality. For example, in areas draining to a lake threatened by excessive P loads, top priority should be given to P control BMPs, even though nitrate leaching to ground water may also be a problem.

BMP systems. A single BMP may not be sufficient to protect water quality in a particular situation. BMP systems may be required to achieve adequate water quality protection. Few practices exist, for example, that can individually reduce bacteria levels in agricultural runoff sufficiently to achieve water quality standards. For this reason, a multiple-barrier approach has been recommended where several BMPs in series act on different aspects of the problem within a farm operation (Rosen, 2000).

5.5 Alternative Uses of Manure

Alternative uses of manure include activities other than using the manure for land application on the operation that produced it. Examples of other uses of manure include exporting manure to other farms, sales of manure for purposes other than for agricultural land application, and use of manure in other products.

5.5.1 Manure export

Producers in some areas, where the amount of manure produced exceeds the land application capacity, export manure. In such cases, manure is sold or transferred off the farm to be used on other agricultural operations where land is available. Some states such as Delaware and Maryland have set up systems of manure trading or brokering to facilitate such transfers. The Delaware Nutrient Management Program operates *Delaware Manure Links* (http://www.state.de.us/deptagri/nutrients/mlinks.htm) To match farmers with excess manure to farmers who can safely use manure for land application or to alternative manure users such as composters. Maryland's Manure Matching Service (http://www.mda.state.md.us/nutrient/manure3.pdf) links farmers with excess manure with other farmers who can safely use the manure as a nutrient source. Farmers may also use the Matching Service to link up with individuals pursuing alternative uses for manure. These may include burning for co-generation of power, fertilizer manufacturing, and composting.

It should be noted that the same management considerations to protect water quality apply to subsequent agricultural users of exported manure as applied to the original producer of the manure.

5.5.2 Non-agricultural land application

Because of its fertilizer value, manure is often used as a fertilizer or soil conditioner in non-agricultural situations where manure nutrients can be recycled. Manure, sometimes mixed with other organic materials, is applied to forested lands, on construction sites and developing land to control runoff and soil erosion (Risse et al., 2003), and as a peat substitute in greenhouses (Inbar et al., 1993). Mukhtar et al. (2003) investigated the combination of coal combustion byproducts and dairy manure as a soil amendment, but found that leaching of metals made the mixture unsuitable as a soil amendment material.

5.5.3 Compost

Composting of animal waste alone can provide a salable consumer product. Animal waste is also an important ingredient in composting operations where other materials are processed. Ball et al. (2000) found that a composted mixture of newspaper and horse manure provided a technology to utilize large quantities of waste paper, while producing a compost that was a viable alternative to peat or coir fiber. Chen et al. (1988) successfully used composted agricultural wastes as a potting medium for nursery stock.

5.5.4 Fertilizer

With processing, animal wastes have been converted into commercial fertilizer products. For example, pelletizing (Hara, 1998) can be done to change the nitrogen and phosphorus ratios to more nearly match the typical plant growth requirements. Nutrients can be injected to adjust the ratio. Pelleted nutrients have reduced moisture content, fewer odors, and reduced transportation costs. Rulkens and Have (1994) proposed central manure treatment facilities in areas of concentrated animal production to extract high value fertilizer suitable for wide distribution.

5.5.5 Other uses

Several other uses have been proposed for manure. Some studies have proposed feeding of some manures, particularly poultry litter, to cattle, but the threat of BSE (mad cow) and other diseases has thrown this idea into some question (FDA, 2004). Combustion of mixtures of poultry litter and coal for power generation has been proposed. Mukhtar (2004) found that a 9:1 blend of coal and poultry litter exhibited fuel quality and cost similar to coal.

Several unusual uses for manure have been discussed or attempted. In 1972, a beef feedlot operator began using its wastes in combination with ground glass to manufacture tile (Calf News, 1972); it is not known if this process developed further. More recently, a researcher proposed a process to refine swine manure into crude oil (Linehan 2004). Other researchers are exploring ways to extract the carbohydrates and proteins from manure to produce commodity chemicals, such as glycols or diols, animal feed, and other higher-value products (PNNL, 2001). It is uncertain if any such exotic processes will achieve cost-effectiveness in the near future, however some may be cost effective in small markets. These markets are easily saturated and this will likely prevent the widespread use of such practices.

5.6 Research Needs

Research needs in manure management fall into two broad areas. First, there are many gaps in our knowledge of the effectiveness of individual management practices. This may be the case for innovative practices that have not yet been widely applied or tested, such as animal treatment for pathogen control and also for practices that have a good theoretical basis but for which data are lacking on real-world applications, such as nutrient management and riparian buffers. Such gaps in our understanding can be addressed by carefully designed experiments conducted at the field or farm scale.

Second, past studies have repeatedly shown that the combined effect of a set of practices implemented across a farm or watershed rarely represents the sum of the effects of individual practices. Thus, there is a great need for comprehensive, holistic research of the effectiveness of overall "good management" on water, soil, and air quality at the farm, watershed, and regional scales. Research that follows each drop of water and each pollutant input to establish the mechanisms and quantify losses from waste production, treatment, and application is needed to truly understand how the effects of various practices add up on the farm and across watersheds. This type of research could entail establishment of a set of model farms where a complete set of practices is implemented. For example, model farms could be designed based upon a rigorous assessment of relative risks, a vision of the "future farm," and an understanding of the "most likely farm." Researchers would identify and quantify all inputs, pathways, and outputs of a broad set of pollutants affecting both air and water quality. Inflow-outflow of pollutants associated with process steps and practices would be coupled with input-output of pollutants from the farms to surface water, subsurface water, tile drains, soils, and the atmosphere to create a thorough understanding of the mechanisms contributing to pollutant loads and load reductions across all media. For example, this research could focus on a system of management practices that could be used to implement a nutrient management plan as required under the 2003 CAFO regulations.

5.6.1 Waste Production

Feeding strategies such as precise diet formulation, enhancing the digestibility of feed ingredients, genetic enhancement of cereal grains and other ingredients result in increased feed digestibility, and improved quality control. Reductions in nutrient content of waste or volumes of waste generated have been suggested as benefits of such strategies for water quality. Most of the research associated with these treatments has been limited to the effects on the animals and in some cases the character or quantity of manure. Questions still exist regarding the effectiveness of optimized feeding programs and optimized crop selection with regard to water quality protection, especially at the watershed level. Further, the effects of optimized crop selection on animal productivity should be better understood and quantified. It is also important to develop a better understanding of the potential for producers who grow much of their own feed to effectively adjust or optimize feed P content.

On a watershed scale, the long-term benefits of feed and crop optimizing strategies should be examined on a mass-balance basis in the context of probable future patterns of livestock production. For example, even if a significant reduction in the P content of poultry litter may be achieved by a new feeding program, the potential gain to water quality might be quickly erased by rapid growth in poultry populations unless additional management measures are undertaken. In contrast, simple changes in dairy feed formulations that reduce the P content of manure may have significant water quality benefits in the long run if animal populations are stable in the watershed. Such issues are best explored through mass-balance analysis, where all inputs, outputs, and transfers of P within a watershed are accounted for.

5.6.2 Waste Collection

It should be noted that except for improvements that reduce the potential for concentrated waste discharges or losses in farmstead storm water runoff, changes in waste collection systems by themselves rarely have major pollution control benefits. Still, there may be opportunities for research into collection approaches that may provide pollution control benefits.

5.6.3 Waste Transfer

In the simplest system, the transfer component is an extension of the collection method. Manure is transported as either a solid or liquid material, and in most cases solid waste is transported before liquid waste because it is less expensive to haul per unit of nutrient moved. Research into the marketing of manure may be beneficial, but this has been done at the state and local level in many areas. It is widely recognized that a reduction of water content and an increase of the N content in manure will increase its value. There may be opportunities to conduct further research into methods to increase the N content while simultaneously decreasing the water content of manure to make it a more attractive commodity

5.6.4 Waste Storage

In general, waste storage alone is not a practice that will protect water quality; it is the management of the stored waste that affects water quality. There are a few exceptions to this principle. First, where storage includes capturing of all farmstead runoff and other wastes such as milking center wastes and silage leachate, waste storage will help eliminate the other sources as discrete problems. Second, waste storage alone is reportedly highly effective in reducing the microorganism content of animal waste. However, regular additions of fresh waste to single large storage structures provide regular inoculations of fresh microorganisms to the stored waste. Additional research and testing is needed to develop compartmentalized or modular sequential storage systems that provide optimum conditions for microorganism die-off. Furthermore, tracking of true pathogens such as *salmonella* and *E. coli* O157:H7 should supplement monitoring of conventional indicator organisms.

Additional research into the effectiveness of litter storage sheds and deep stacking of poultry litter is needed. Further, a better understanding of the effectiveness of batch versus continuous input approaches to storing waste in structures may lead to changes in how waste flow is managed. Research into the nature and extent of airborne particulates generated from stockpiled manure is also needed.

The loss of nutrients and runoff from uncovered manure piles can be problematic. Additional information on practical temporary methods for covering these piles would help farmers and environmental professionals. Information on the costs and impact on manure nutrient content of biologically inert coverings may promote their use.

5.6.5 Waste Treatment

In general, much is still to be learned regarding the cost and effectiveness of manure digestion/treatment options, including the following:

1. Anaerobic digesters for methane production and recovery
2. Secondary biological treatment
3. Sequencing batch reactors
4. Gasification
5. Pyrolysis

The use of sequencing batch reactors (SBRs) to treat dairy waste has been studied in the laboratory and shown to be effective in reducing pollutants in the liquid portion of dairy waste. However, reports have lacked specific information on sludge characteristics or P removals (Johnson and Montemagno, 1999; Zhang et al., 1999).

Reports of the effectiveness of composting for pathogen reduction have been conflicting. If properly managed, composting may offer significant initial reductions of bacteria numbers due to high temperatures, but regrowth of bacterial populations after temperatures decline has been reported. Additional research is needed to better define and guide the reliability and consistency of composting for pathogen removal.

Recently, interest has increased in the use of amendments or treatments to stabilize P in animal waste to less soluble forms and thereby decrease the risk of soluble P losses following land application of waste. Early research has been limited, raising questions about long-term effectiveness, potential side effects (e.g., metals in runoff), cost, and applicability of such innovations. These treatments include the use of water treatment residuals such as alum sludge or alum hydrosolids; ferric chloride additions to poultry litter; the addition of fluidized bed combustion flyash (FBC) and flue gas desulfurization product (FGD) to soils; the addition of zeolite (primarily Si, AL, Na, and K oxides) to dairy slurry; the application of polyacrylamide (PAM) to soils receiving manure; and the use of 2% fine limestone dust to separate P from manure. In addition, while aluminum sulfate ($Al_2(SO_4)_3$) – alum - is the most thoroughly evaluated manure amendment, some authors have called for more research into the long-term solubility of metals such as As, Cu, and Zn in soils receiving alum-treated wastes. The majority of the alum studies have focused on the effects on P solubility and runoff. Additional research into the effects on nitrogen volatilization and runoff of metals may be warranted. Further, some researchers have cautioned that decreases in P solubility in applied waste will not alter the total mass of P applied and have called for additional research on the long-term solubility of P in soils receiving alum-treated animal waste (Sims and Luka-McCafferty 2002).

Various chemical treatments have been proposed to reduce the levels of pathogens and other microorganisms in animal wastes. Again, research has been very limited, raising questions about their the effectiveness, cost, and applicability of many of these treatments. Such treatments include biosecurity practices; the use of chlorate ($NaClO_3$) to reduce *E. coli* in cattle prior to slaughter; the use of lime materials (calcium oxides) to reduce pathogens and odor in animal waste; the use of lime as a disinfectant for barn and milking center floors, for disease control in carcass disposal, and for disinfection of animal wastes; and the use of carbonate and alkali to eliminate *E. coli* from dairy cattle manure.

Reports of vegetated filter strip (VFS) effectiveness vary widely and the majority of studies have been conducted on research plots or very controlled conditions. Concentration reductions and mass retention of solids and nutrients of 70 percent to more than 90 percent have been reported under favorable conditions, but pollutant reductions of less than 30 percent have been reported in some studies. VFS treatment effectiveness can diminish rapidly under hydraulic overload or in cold climates, so research is needed to quantify the effectiveness of VFS under a range of expected real-world field conditions. In addition, enhancements or alternative designs to VFS should be researched for application to colder climates or hydraulic overloads. Research is also needed to better quantify the real-world performance of riparian buffers, especially to address the issue of concentrated overland flow “short-circuiting” buffer systems.

5.6.6 Waste Utilization

Questions still exist regarding the influence of waste application method on bacteria losses (Jamieson et al., 2002). Although manure injection has been reported to reduce surface losses of indicator organisms, subsurface injection may reduce manure contact with surface soils and tend to increase bacteria transport to tile drains or ground water. Research is also needed to test the relationship between indicator organisms and pathogens given that the transport efficiencies of various microorganisms may vary due to macropores.

The application of manure to frozen and snow covered ground has been studied extensively. However, little practical guidance is available to farmers and environmental professionals on this subject. Research is needed to identify under what conditions application of manure to frozen or snow covered ground would not result in significant loss of nutrients and runoff to surface waters.

Additional research in the area of agricultural policy could include investigating the barriers and potential solutions to the mixing of manure from CAFOs with biosolids. Currently the handling and use of biosolids is more tightly regulated than the use of manure. This situation has the potential to discourage the handling and mixing of these materials.

5.6.7 Tile Drainage

It is now recognized that preferential flow paths - macropores - in the upper soil horizons can easily transmit microorganisms and particulate matter to tile drains (Simard et al., 2000; Jamieson et al., 2002). Further, because protozoans such as *Cryptosporidium* and *Giardia* are similar to indicator bacteria in size range (Pask, 1994), the occurrence of indicator bacteria in tile drainage may also indicate the presence of these pathogens. Jamieson et al. (2002) proposed several management strategies to minimize leaching of microorganisms:

- Animal wastes should not be applied when tile drains are already flowing or within 72 hours of a runoff event;
- Subsurface injection may reduce runoff losses but may increase risk of bacterial movement in drainage water;
- Disturb the top soil layer to break up macropores to reduce delivery of microorganisms to tile drainage system;
- Plug drainage lines and allow them to fill with water prior to land application of waste to prevent direct entry of wastewater into the lines; and
- Avoid spreading waste directly over drainage lines.

Potential areas of research include testing the suitability of indicator organisms to demonstrate the presence of pathogens in tile drains, as well as testing the effectiveness of management strategies such as those proposed above to minimize leaching of microorganisms.

5.6.8 Costs and Applicability

The cost-effectiveness and practicality of various animal treatment options for pathogen reduction is largely unknown, due largely to the fact that the effectiveness information is sketchy. The potential for marketing compost products has been studied, but research into a much broader range of applications may be warranted.

5.6.9 Alternative Uses of Manure

The alternative uses of manure explored to date are largely limited to exporting manure to other farms and applying the manure in some form to non-agricultural lands. Combustion of mixtures of poultry litter and coal for power generation has been proposed and the use of beef feedlot wastes in combination with ground glass to manufacture tile was at least considered. Other researchers have proposed a process to refine swine manure into crude oil and explored ways to extract the carbohydrates and proteins from manure to produce commodity chemicals, such as glycols or diols, animal feed, and other higher-value products. Little else has been considered, however, leaving this as one of the most needed areas of research.

5.7 References - See References in Section 6 Environmental Risk Management Methodologies and Approaches